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noranda

SULPHIDE DUST EXPLOSION

PROCEEDINGS OF A WORKSHOP SPONSORED BY
NORANDA MINERALS INC.
GECO DIVISION AT MANITOUWADGE, ONTARIO
OCTOBER 23 AND 24, 1986

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Canada

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FOREWORD

In October 1985, a sulphide dust explosion occurred at the Geco Division Mine of Noranda Minerals Inc., which resulted in a fatality. This was the first serious incident of this type at Geco in 31 years of operation. The circumstances were examined in detail by Geco with the assistance of a number of outside specialists, particularly by Dr. Roger Enright of the University of Sydney (Australia), who has conducted previous investigations of this type of incident.

A paper by K. Byberg of Geco was presented at the 1986 *Mine Accident Prevention Association of Ontario* Annual Meeting in Toronto, 29 May 1986, which detailed the findings.

As a further step to promote awareness of the risks of sulphide dust explosions, and possibly to help identify better prevention techniques, Geco decided to organize a *Sulphide Dust Explosion Workshop*. In addition to a series of presentations by Dr. Enright, case histories and technical papers were given by six other speakers.

The 50 participants at the *Workshop* inlcuded representatives of major Canadian mining companies, regulatory agencies, explosives manufacturers, CANMET, USBM, and several universities.

This report contains the written submissions, an outline of Dr. Enright's presentations, and the conclusions reached by participants. We hope that the wide distribution of this information will reduce the risk of such occurrences in the mining industry.

The *Workshop* was an excellent opportunity to discuss the state-of-the-art and need for further work. More important, there was a commitment by Geco to coordinate information exchange on this topic for the next two years, and on the part of other participants to work together in the development of improved technology.

John E. Udd
Director
Mining Research Laboratories
CANMET
Energy, Mines & Resources Canada

P.C. McLeod
Vice President Operations
Geco Division
Noranda Minerals Inc.
Canada

AVANT-PROPOS

En octobre 1985, une explosion de poussières de sulfure se produisit à la division minière Geco, de Noranda Minerals Inc. causant un mort. C'était le premier accident sérieux de ce type à Geco en 31 ans d'opération. Les circonstances furent examinées en détail par Geco avec l'assistance de nombreux spécialistes de l'extérieur, particulièrement le Dr Roger Enright de l'université de Sydney (Australie), qui a dirigé plusieurs investigations précédentes pour ce type d'accident.

Un article par K. Byberg de Geco a été présenté au congrès annuel de l'association ontarienne pour la prévention des accidents dans les mines (MAPAO) à Toronto, le 29 mai 1986. Celui-ci y décrit les résultats de l'étude.

Pour sensibiliser l'industrie et possiblement pour aider à identifier de meilleurs techniques de prévention, Geco a décidé d'organiser un atelier sur les explosions de poussières de sulfure. En plus d'une série de présentations par le Dr Enright, des histoires de cas et divers papiers techniques ont été donnés par six autres participants.

On comptait parmi les 50 participants à l'atelier, des représentants des plus importantes compagnies minières canadiennes, des agences de réglementation, des manufacturiers d'explosif ainsi que CANMET, le USBM et plusieurs universités.

Ce rapport contient les soumissions écrites, les grandes lignes de présentation du Dr Enright, ainsi que les conclusions auxquelles sont parvenus les participants. Nous espérons que la vaste distribution de cette information contribuera à réduire les risques de tels incidents dans l'industrie minière.

Cette réunion a été une excellente occasion pour discuter des connaissances actuelles et des besoins futurs en recherche. Mais plus important, il y a eu engagement de la part de Geco pour coordonner l'échange d'information sur le sujet pour les deux prochaines années, et de la part des autres participants pour travailler ensemble au développement d'une technologie améliorée.

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Vice-président d'opérations
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University of Sydney, Australia

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Université de Sydney (Australie)

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(Reprinted from the Proceedings of the 13th Commonwealth Mining and Metallurgical Congress, Singapore, May 1986/Compte rendu du 13^{e} Commonwealth Mining and Metallurgical Congress, Singapour, mai 1986-Réimpression)

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INTRODUCTION

Subsequent to the *Workshop* on Sulphide Dust Explosions, it was agreed by CANMET and Noranda that an edited *Proceedings* should be prepared and widely distributed. to increase awareness of these incidents in the industry.

At the *Workshop* written papers were provided by some of the presenters, while in other cases only a limited, or no text was available. These *Proceedings* are, therefore, organized as follows:

(1) the full text of the *Technical Papers* and *Case Histories*, as received from the authors, is presented;

(2) Professor R.J. Enright's presentation notes are included (CANMET is proposing to contract Prof. Enright to prepare a full text for subsequent publication);

(3) the *Conclusions* and *Actions* agreed to at the *Workshop* are listed, and an update (taken to April, 1987) is presented:

(4) in *Appendix 'A'*, the *Agenda* and *List of Participants* are provided:

(5) in *Appendix 'B'*, the *Summary* and detailed *Notes*, as prepared by Geco, are appended for reference. These include *Summaries* of several oral presentations not otherwise recorded;

(6) because of copyright considerations, published papers are not included. However, an extensive *Bibliography* is included at the end of Paper I.5.

The text of the presentations are reproduced *as received*. They may contain errors, and do contain contradictory statements. The editors do not accept responsibility for the views expressed.

The major contribution to industry by Ken Byberg and by Geco management, in conceiving and successfully implementing this important *Workshop*, is acknowledged.

E.D. Dainty and L.B. Geller
Research Scientists,
Energy, Mines and Resources Canada,
CANMET, Mining Research Laboratories

K. Wheeland
Head,
Dept. of Env. Technology
Noranda Research Centre

INTRODUCTION

Subséquemment à l'atelier sur les explosions de poussières de sulfure, CANMET et Noranda se sont entendu pour préparer et distribuer un compte rendu de façon à accroître la sensibilité de l'industrie à ce type d'accident.

À cette réunion de travail, divers articles ont été fournis par quelques-uns des orateurs alors que dans d'autres cas, il existait seulement une version écourtée ou aucun texte n'était disponible. Ainsi, le compte rendu est structuré de la façon suivante:

(1) le texte intégral des articles et histoires de cas, tel que reçu des auteurs, est présenté;

(2) les notes de présentation du professeur R.J. Enright sont inclus (CANMET propose d'allouer des fonds au professeur Enright pour préparer un texte intégral à être publié);

(3) les conclusions et actions convenues lors de l'atelier sont énumérées et une mise à jour (avril 1987) est présentée;

(4) dans l'Annexe 'A', l'ordre du jour et la liste des participants sont fournis;

(5) dans l'Annexe 'B', un résumé et des notes détaillées, tel que préparé par
Geco, sont ajoutés pour référence;

(6) pour des considérations de droits d'auteur, les articles publiés ne sont pas inclus. Toutefois, une bibliographie exhaustive est incluse à la fin de l'article I.5.

Le texte des présentations a été reproduit tel que reçu. Elles peuvent contenir des erreurs et contiennent des déclarations contradictoires. Les éditeurs n'acceptent aucune responsabilité pour les opinions exprimées.

La conception et l'implantation réussie de cet important atelier constitue un apport majeur à l'industrie grâce aux efforts reconnus de Ken Byberg et de la direction de Geco.

E.D. Dainty et L.B. Geller
Chercheurs scientifiques,
Énergie, Mines et Ressources Canada
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Chef, Dép. de technologie
de l'environnement
Centre de Recherche Noranda

PART I

Technical Papers and Case Histories

NORANDA MINERALS INC.

GECO DIVISION

MR. K. G. BYBERG - CHIEF MINE ENGINEER

SULPHIDE DUST EXPLOSIONS AS REFERENCED TO THE GECO OPERATIONS OF NORANDA MINERALS INC., MANITOUWADGE, ONTARIO.

K.G. BYBERG
CHIEF MINE ENGINEER

Presented at the 1986 M.A.P.A.O. Annual Meeting, Toronto, Ontario.

May 29, 1986.

The Geco Division of Noranda Minerals Inc. lies in the Canadian Shield approximately 400 km northeast of Thunder Bay and mid way between the two trans Canada highway routes 17 and 11.

Discovered in 1953, the sulphide deposit has to date produced over 42 million tons of Cu, Zn, Ag, and Pb ore. Grades have averaged 1.88 Cu, 3.75 Zn and 1.69 oz/ton Ag from an orebody plunging at 35 degrees to the east from an outcropping on surface. This area just north of Manitouwadge Ontario, took the name of, and was known in earlier years to the native indians as "Cave of the Great Spirit".

Presently the Geco operation mills 4100 tons per calendar day, mined at a rate of 5740 tons per day during a five day week.

ABSTRACT

Prior to October 1985, sulphur dioxide gas undergound at Geco was limited to a few small occurrences which were considered part of the blasting gases resulting from the use of explosives and were dealt with in a similar fashion.

The occurrence of a major sulphide dust explosion on October 8, 1985 was a first for Geco and changed the methods and outlook towards this phenomenon.

This paper deals with the events leading up to the occurrence, the results of the investigation by Company officials and causes relating to the event.

Also included is a general theoretical outlook on sulphide dust explosions, and a practical approach to alleviation.

Acknowledgement is gratefully given to Geco staff, operating and engineering, and externally to Mr. K.G. Wheeland, Head, Department of Environmental Technology, Noranda Research and Dr. R.J. Enright, Acting Head, Mining Engineering, University of Sydney, Australia. An expert in this field, Dr. Enright from abroad analysed the Geco occurrence, tabulated and analysed the information some of which is included herein.

RÉSUMÉ

Avant octobre 1985, le dioxyde de soufre souterrain à la mine Geco était limité à quelques petites manifestations qu'on considérait comme faisant partie des gaz de tir résultant de l'utilisation des explosifs et qu'on traitait en conséquence.

L'important coup de poussières sulfurées , survenu le 8 octobre 1985, a littéralement secoué la Geco : il a déclenché un changement des méthodes et modifié la façon dont le phénomène est perçu.

La présente communication expose les événements qui ont abouti au coup de poussières, les résultats de la recherche effectuée par la société et les causes de l'incident.

La communication contient aussi un exposé théorique général sur les coups de poussières sulfurées et propose une méthode commode d'alléger le problème.

Nous tenons à remercier vivement le personnel d'exploitation et d'ingénierie de la Geco ainsi que M. K.G. Whelland, chef du département de technologie de l'environnement, Recherche Noranda, et M. R.J. Enright, chef intérimaire, Génie minier, Université de Sydney, Australie. Expert dans ce domaine, M. Enright a étudié le coup de poussières survenu à la Geco, mis sous forme de tableau et analysé les données obtenues dont certaines sont livrées dans cette communication.

GEOLOGY

The Manitouwadge mining camp of which Geco is the largest mine, is located near the contact of Abitibi-Wawa Metavolcanic Belt and the Quetico Metesedimentary Belt and is thought to be approximately 2.7 billion years old. Geco is found on the southern limb of the Manitouwadge Synform (overturned anticline) in a package of steeply dipping easterly plunging rocks. The orebody at Geco has been interpreted to be a sedimentary, stratabound, stratiform orebody, primarily hosted in a group of rocks known as the Sericite Schist Group. It is stratigraphically underlain by an altered mafic volcanic group known as the Granite Gneiss Group and overlain by a sedimentary sequences of altered greywackes and iron formations known as the Grey Gneiss Group

The Main Orebody is found within the Sericite Schist and is composed of massive pyrite, pyrrhotite, sphalerite, chalcopyrite and minor galena. It is surrounded by disseminated sulphides (primarily pyrite, pyrrhotite and chalcopyrite) hosted in sericitic rocks.

THE GECO METHOD

The Geco 55 million ton main orebody is serviced by two main surface shafts, No.1 and No.4, approximately 1.3 km apart. Figure 1 is a longitudinal projection of the Geco Main Orebody.

Although many mining methods have been utilized during its' life, the most successful and major method presently employed is the "Tight-Fill Blasthole Method". Stopes designed 70 ft with pillars 120 or 150 ft in width are mined in 400 ft lifts. The ore is drilled from 100 ft levels across the orebody ranging 50 to 300 ft transversely. In narrower stopes predominantly near surface, mining is performed longitudinally. Slots are created in strategic locations the full height of the mining block into which longhole blasting takes place creating an optimum void of 20% of the block volume. The "Final Blast" is fired into the void and broken muck removed through scrams by large 125 H.P. electric slushers to mill holes and ore passes, leading to one of the three crushers.

During mining, quarried rock fill is introduced on surface via fill raises extending to the stope or pillar. As ore is removed under a sequenced draw control program, the quarried waste takes the place of the ore and provides wall support on a continuous basis. After all ore has been recovered, tailings in slurry form are introduced and where necessary a 30:1 cement mix further fills and consolidates the mined out areas.

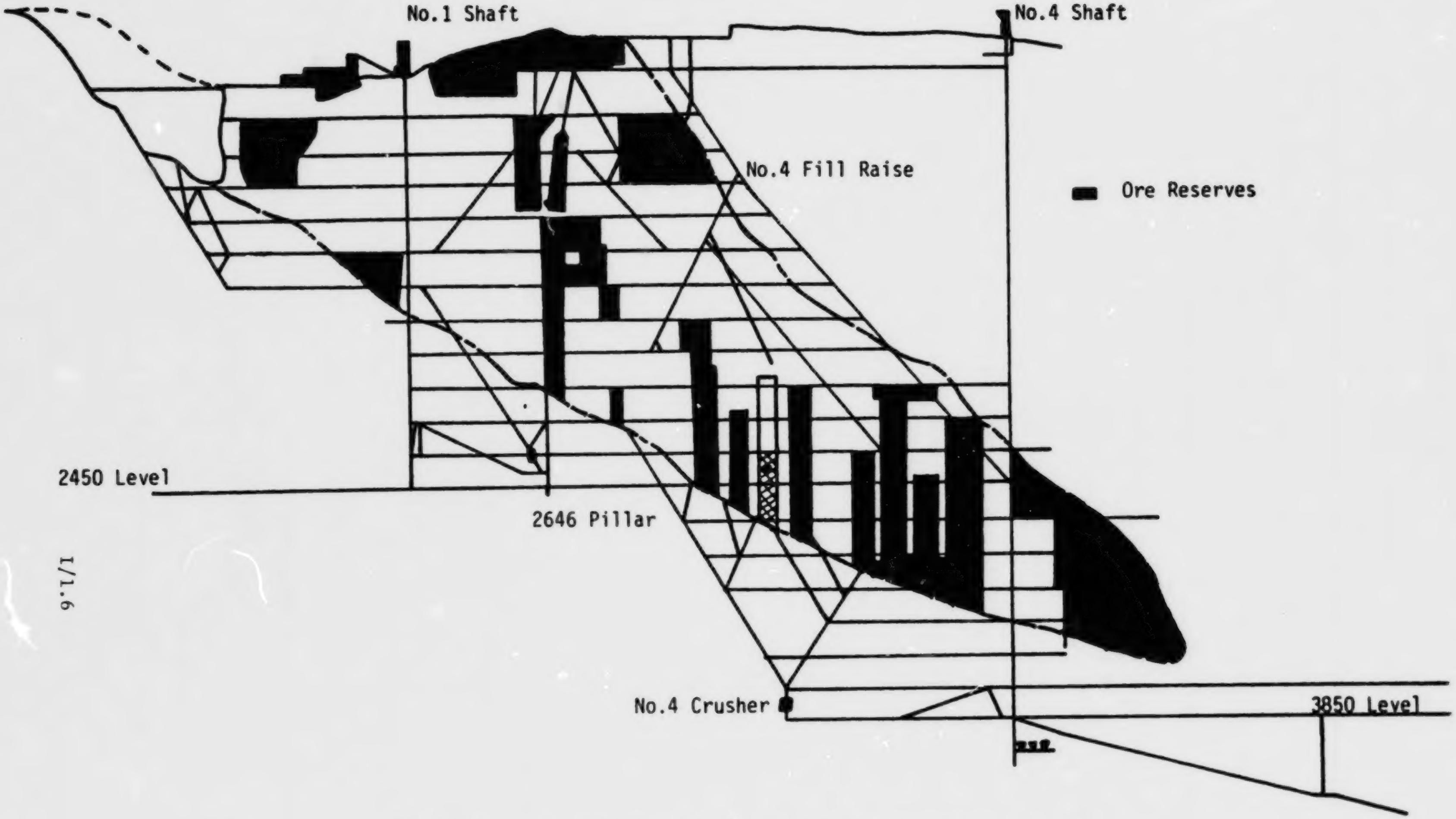

No.1 Shaft
No.4 Shaft
No.4 Fill Raise
Ore Reserves
2450 Level
2646 Pillar
No.4 Crusher
3850 Level

FIGURE 1 Longitudinal Projection of the Geco Main Ore Body

VENTILATION

Designed as a Push-Pull System, in excess of 500,000 c.f.m. of air enters and is exhausted from the underground workings via fresh air and return air systems. At the No.1 Shaft, a Fresh Air Raise provides 200,000 c.f.m. while the No.4 Shaft itself being a fresh air source contributes 300,000 c.f.m. Return air is via a 54" column in the No.4 Shaft as well as a return air raise system at the No.1 Shaft. Fresh air from the two sources is integrated where required.

Large electric fans on various levels push fresh air from the source along the levels and where required through the workings and into the return air system at the stopes' extremity.

2646 PILLAR

The 2646 Pillar which is 120 ft wide, 400 ft in height and ranges between 200 and 250 ft transversely is bounded on the west by the 2645 and the east by the 2747 Stope and above by the 2246 Pillar. Figure 2 is an artist's conception of the pillar after blasting is complete.

The two adjacent stopes had been mined by the Geco Blasthole Method, filled with quarried waste and consolidated with a 30:1 tailings/cement slurry. The 2246 Pillar above had also been mined with the ore removed while simultaneously filling with quarry rock. Waste rock in the 2246 was therefore "Mobile" providing support while awaiting the final blast in the 2646, into which the 2246 waste rock would drop.

Mining of this area surrounding the 2646 had produced some 2.2 million tons without a significant sulphide dust incident. The 2646 Pillar itself graded 1.2% Cu, 6.5% Zn and 1.2 opt Ag and contained block contents of 40.8% pyrite, 3.5% chalcopyrite, 5.7% pyrrhotite and 9.8% sphalerite. Sulphur content was estimated at 28.3% . Statistical data of the area is provided by Table 1.

Development for mining the 2646 Pillar began in 1983, and by October 8, 1985, was completed. 4 1/2" downhole and 3" undercut uphole drilling also was complete as was 80% of slot or void blasting leading to the "Final Blast". Figures 3 through 7 show typical views of the pillar, the development horizons and slot blasting completed by October 8, 1985.

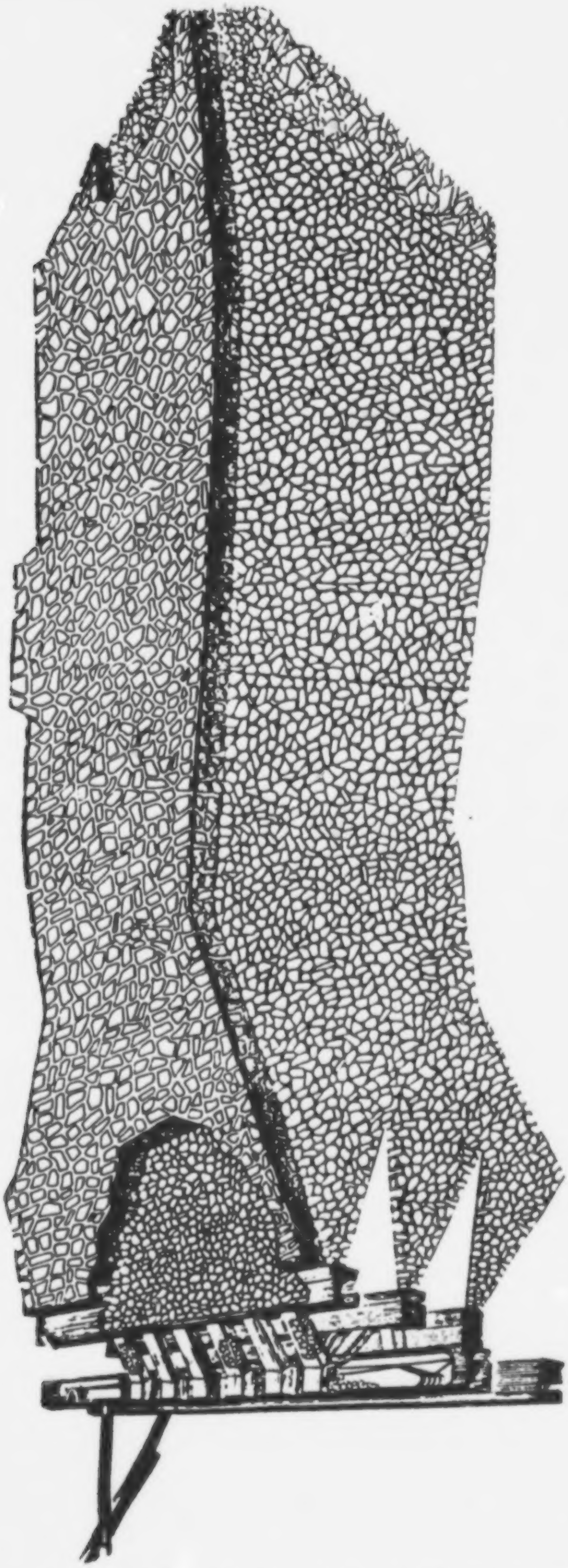


FIGURE 2 3-D View of 2646 Pillar After Blasting Complete

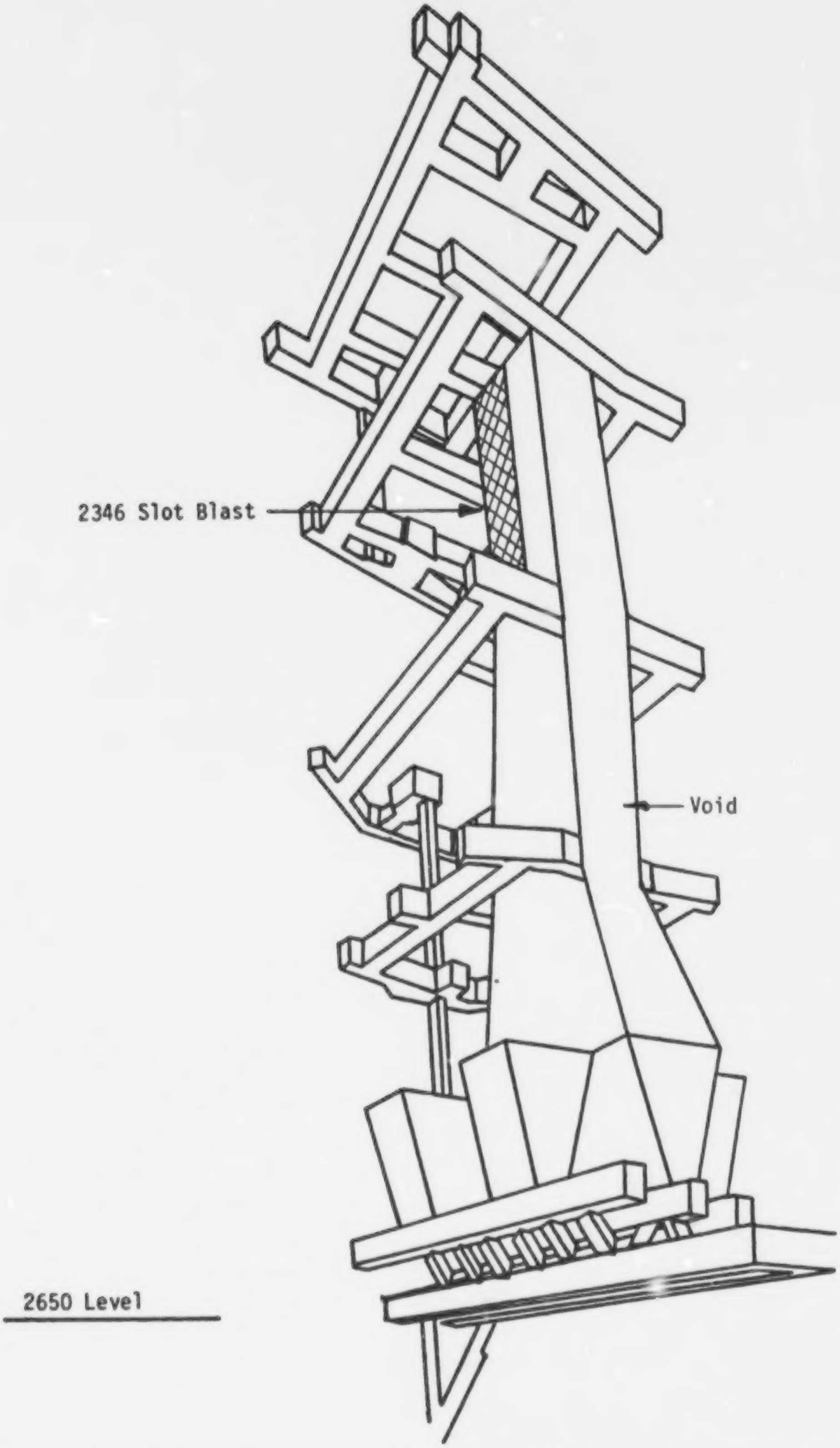

2346 Slot Blast
Void
2650 Level

FIGURE 3 Three Dimensional View of 2646 Pillar Showing Void and 2346 Slot Blast

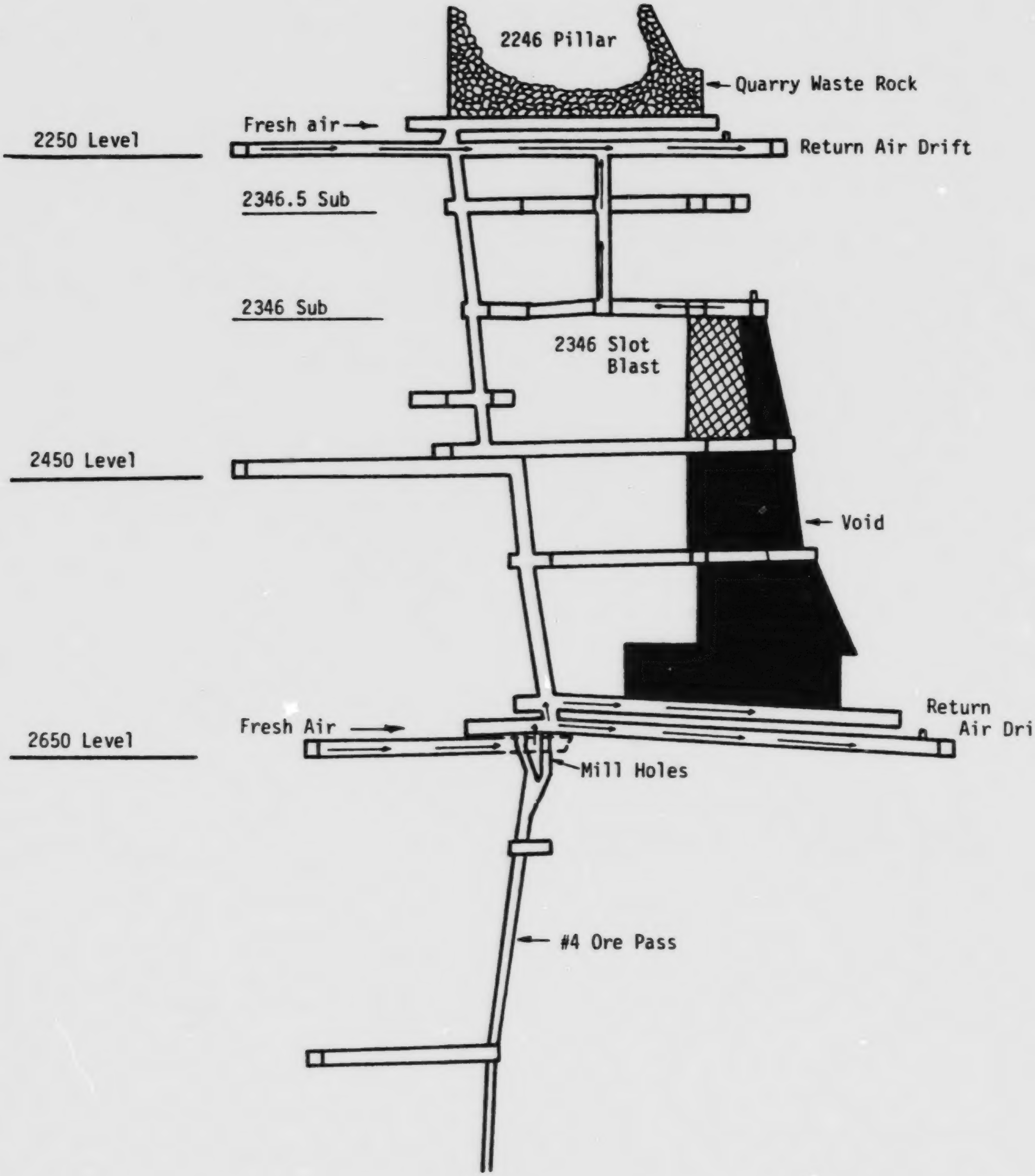

2246 Pillar
Quarry Waste Rock
Fresh air
2250 Level
Return Air Drift
2346.5 Sub
2346 Sub
2346 Slot Blast
2450 Level
Void
Return Air Dri
Fresh Air
2650 Level
Mill Holes
#4 Ore Pass

FIGURE 4 2646 Pillar - Side View Showing Void and 2346 Blast

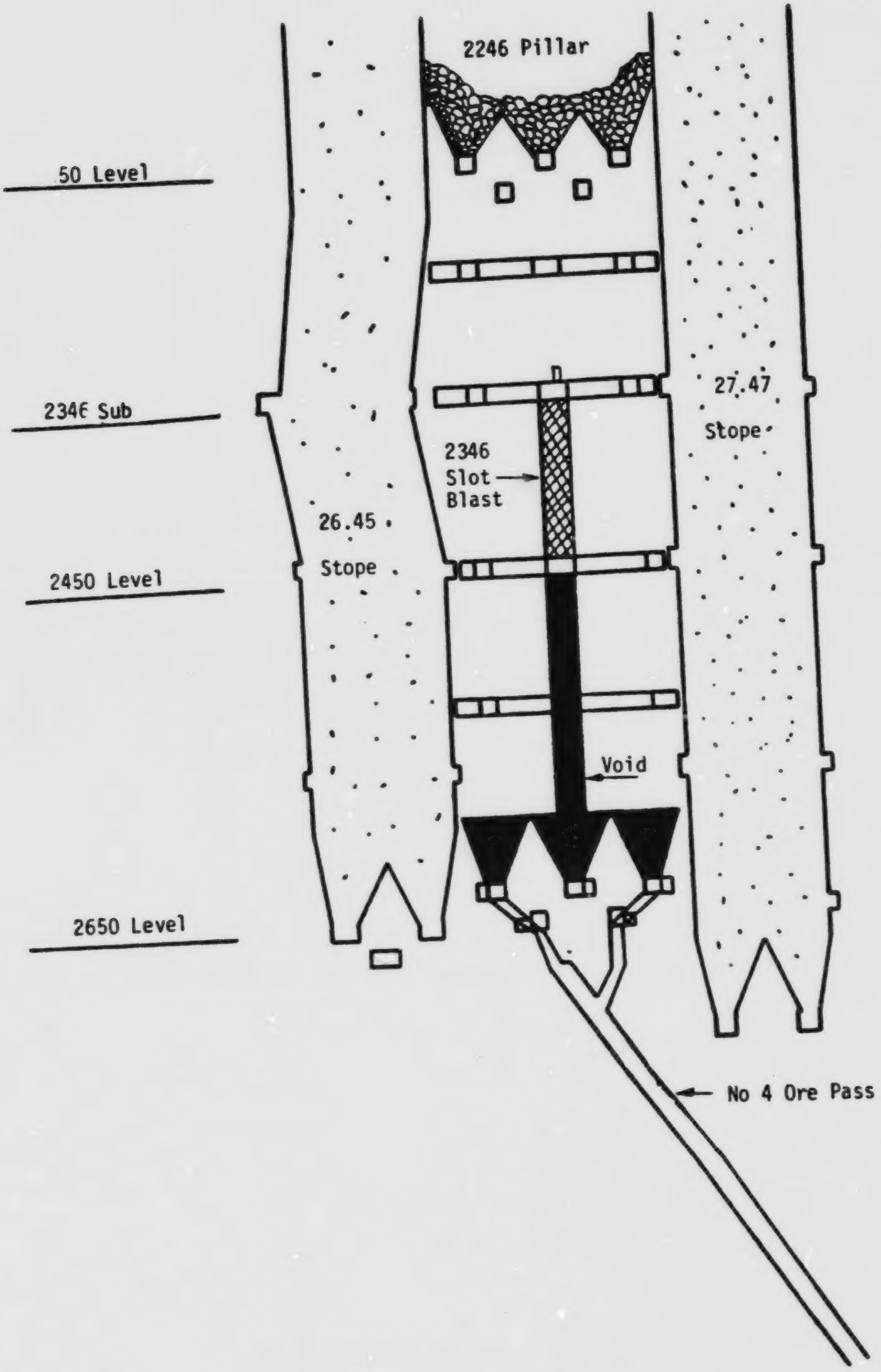

2246 Pillar
50 Level
2346 Sub
27.47
Stope
2346
Slot
Blast
26.45
Stope
2450 Level
Void
2650 Level
No 4 Ore Pass

FIGURE 5 Front View 2646 Pillar Showing Void and Slot Blast

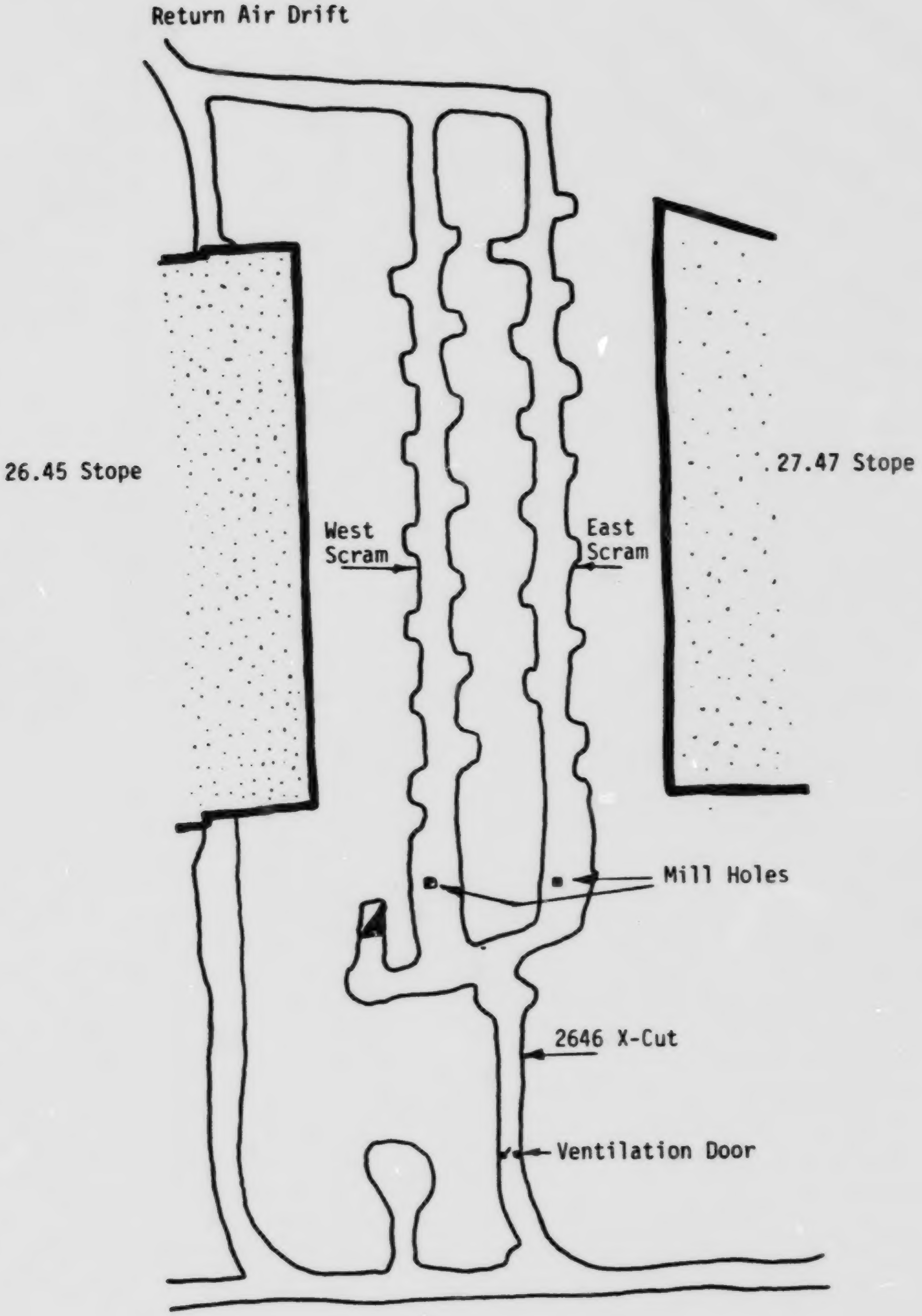

Return Air Drift
26.45 Stope
27.47 Stope
West Scram
East Scram
Mill Holes
2646 X-Cut
Ventilation Door

FIGURE 6 Plan View of 2646 Scram (2650 Level)

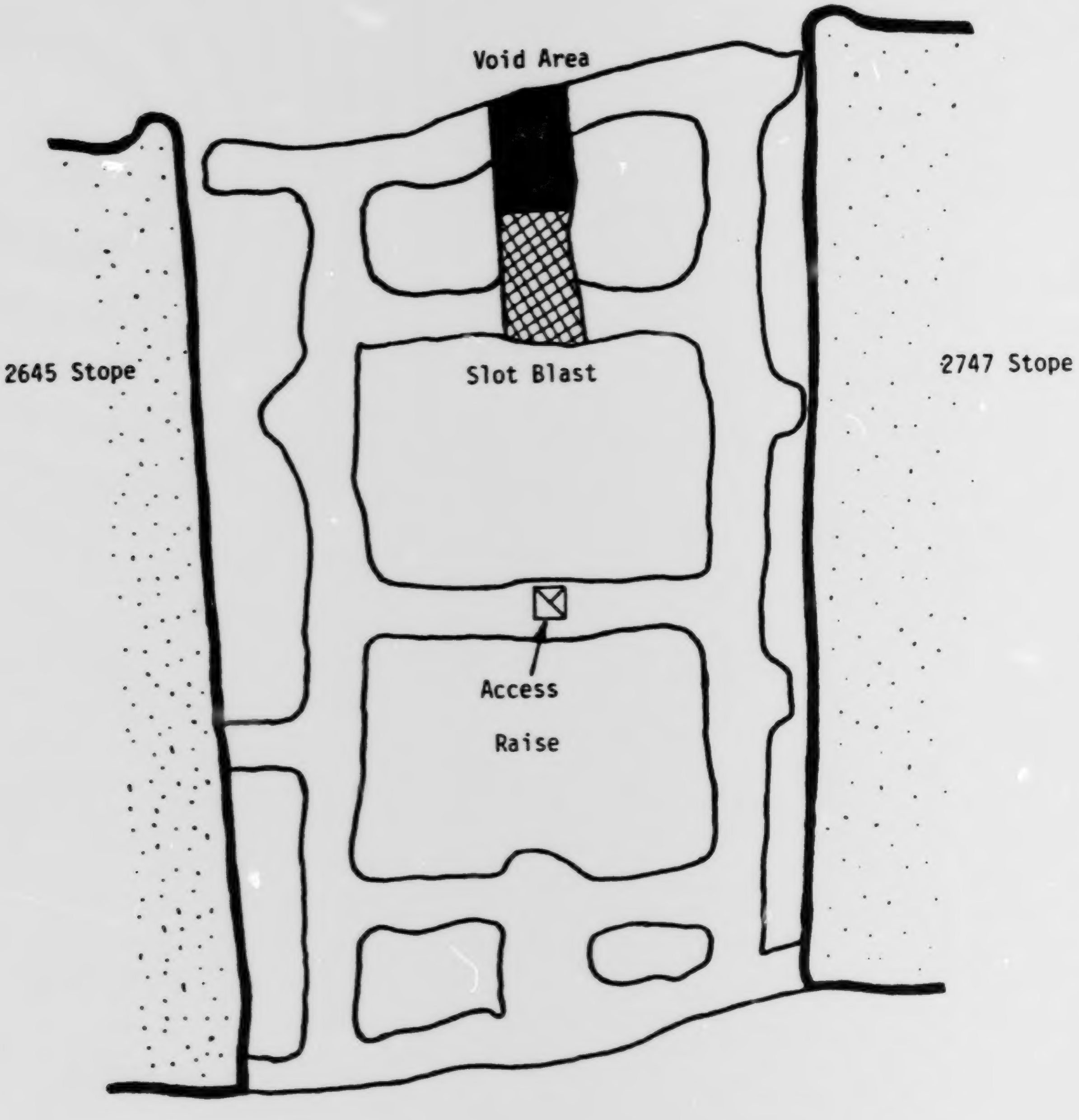

Void Area
2645 Stope
Slot Blast
2747 Stope
Access
Raise

FIGURE 7 Plan View of 2346 Sub Level

STOPE	TONS	GRADE			
		CU(%)	ZN(%)	AG(OPT)	S(%)
22-45	279 000	2.7	7.5	1.9	21.0
26-45	693 000	1.2	5.0	1.2	30.4
22-47	216 000	3.0	6.8	1.7	20.4
27-47	675 000	1.3	6.9	1.3	25.3
22-46	404 000	2.7	6.6	1.8	21.9
TOTAL	2 267 000				
26-46	927 000	1.2	6.5	1.2	28.3

TABLE 1 2646 AND SURROUNDING AREA STATISTICS

Blasting of the 2646 slot and undercut began in May 1985 and from a total of 22 blasts had produced 100,907 tons. Remaining in the area to be voided was the slot raise between 2346.5 and 2346 Sub Levels as well as the slot enlargement above and below the 2346 Sub Level. This area remaining was later to require 13 blasts to complete the void.

On October 8, 1985 at 11:55 p.m. the 23rd longhole void blast was fired from surface. Statistics are shown on Table 2, which include 4840 lbs explosives, 15 reinforced nonels, delays Nos. 4 to 19, producing 3500 tons of ore. As well and not a common occurrence, the 2346.5 Drop Raise (slot) immediately above the void blast was fired sequentially.

SLOT BLAST

Anfo	4510 lbs
Water gel	330 lbs
TOTAL	4840 lbs
Tons	3500
Caps	NONEL #4 to #19

Blast Duration = 925 ms

DROP RAISE - CUT

Watergel	110 lbs
Tons	11
Caps L.P. Electric	1 TO 4

Blast Duration = 910 ms

TABLE 2 2346 SLOT BLAST

The detonation of this blast triggered a secondary sulphide dust explosion of such magnitude never before experienced at Geco.

The blast was fired from surface between the 4-12 and 12-8 shift change when the 4-12 crews had been hoisted and prior to the 12-8 shift being lowered underground. This was the case in all longhole blasts due to the ease of clearing and guarding, a labour intensive task in any Geco type blasthole method were crews to remain underground.

The contradiction to this rule was a development crew of three working on 3850 level approximately one mile east of No.4 Shaft and some 7400 ft from the blast being initiated. This crew, for accessibility reasons worked a non standard shift beginning at 6:00 p.m. each evening.

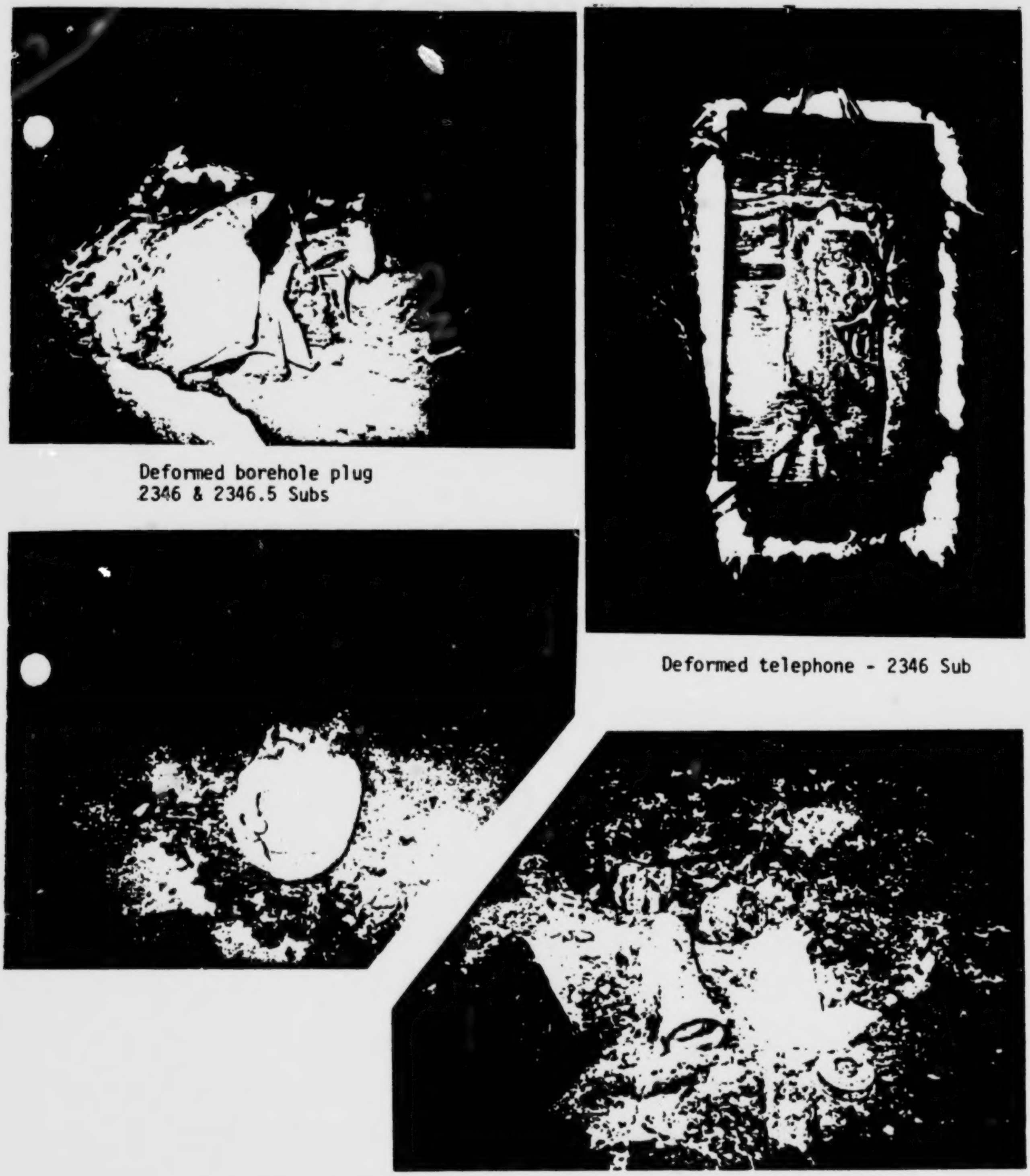
Table 3 illustrates the sulphur content of the void blast.

2.7% CHALCOPYRITE $CuFeS_2$		1.0% S
12.2% SPHALERITE ZnS		4.0% S
45.0% PYRITE FeS_2		24.0% S
6.6% PYRRHOTITE $Fe\ S$		2.4% S
	TOTAL	31.4% S

TABLE 3 2346 VOID BLAST SULPHUR CONTENT

The sulphide explosion as evidenced afterwards, occurred on the 2346 Sub Level, and the flame front, may have in fact reached the 2650 Level and ore pass and burned within that cavity also. Extreme heat was evidenced on the 2346 Sub, and to a lesser degree on the 2346.5 and levels below. Plastic borehole plugs, lead wire, telephone, combustible materials as shown by the photographs on Figure 8 were either badly burned or deformed by heat. Spontaneous combustion ignited a fire in the 2346 Sub which burned until self extinguished. So intense was the heat in this area that the back and walls contained a white residue.

The explosion itself was of such magnitude that the ventilation was reversed momentarily. On the 2650 Level the incasting 40,000 c.f.m had no effect on the explosion. A 1 1/2" ventilation door located in the 2646 X-Cut 400 ft from the blast and open at the time, was ripped from its concrete moorings and deposited in rubble against the main drift wall 50 ft away. Large pieces of it were found up to



Deformed borehole plug
2346 & 2346.5 Subs

Deformed telephone - 2346 Sub

Fire Area 2346 Sub

FIGURE 8 Typical Photograph of damage caused by Heat of Flame Front

540 ft away hurtled against the 40,000 c.f.m. travelling in the main drift. Air ripples on the drift floor similar to waves on a sand beach were found throughout the 2250, 2450 and 2650 Levels, however they were more prevalent on the 2650 Level, where the windswept evidence was easily detected up to 1400 ft from the blast also towards the 40,000 c.f.m ventilation flow. The manway between the 2250 Level and 2346 Sub also was damaged and required repairs. A heavy "soot-like" residue was found throughout the 2646 area from the 2650 to 2250 Levels. This residue varied in texture, size, colour, and amounts with location. Closer to the blast on the 2346 and 2346.5 Sub Levels, the dust was black and in some areas reddish brown, up to 1/8" in thickness and relatively coarse. More distant from the blast location on the 2250, 2450 and 2650 Levels in the pillar area the dust residue was very black and of fine grain size. Thickness was estimated at 1/16".

The dust explosion we now know occurred as a result of the 2346 void blast. Evidence showed that the flame front originated on the 2346 Sub and moved throughout the area even to near the 2646 Mill Holes leading to the ore pass. Whether sufficient sulphide fuel was available to feed the flame front in the ore pass is not known.

The explosion reversed momentarily the ventilation certainly in the blast area, including the normally upcasting ore pass and mill holes, and forced the resultant SO2 gas down the ore pass 1000 ft to the No.4 Crusher. Prior to the blast on the 4-12 shift, the headblock at the No.4 Crusher had been reported full. After the incident there was a measured 60 ft of muck above the chains. Evidence shows there was muck in the ore pass at the time of the incident, through which the SO2 gases were forced, however the amount is unknown. Conditions found in the Crusher Station were not abnormal with the exception of a significant amount of relatively coarse, unaltered dust throughout, thereby substantiating the theory that a rush of air had passed by.

The SO2 gases were now in the Crusher's return air system and due to the additional volume of air forced from the ore pass, moved rapidly along the 3850 Level to the No.4 Shaft return air column. The quantity of contaminated air far exceeded the normal 17,000 c.f.m. flowing from the crusher (7000 in line and 10,000 free flow). Consequently some of the contaminated SO2 bearing air was pulled into the 44,000 c.f.m. fresh air fan at the 4 Shaft Station and forced east to the development heading where the three men were working. One miner was fatally injured. The remaining two who sustained respiratory injuries provided themselves with air from a compressed air header within 300 ft of the face until mine rescue crews arrived.

The ventilation problem had further been aggravated as the drift heading's return air fan located at the No.4 Shaft 3850 Level Station had been turned off, hence only 35% of the return air from the heading was exhausted to surface, while the remainder recirculated.

First indications of the problem came from the oncoming 12-8 crews in the 3650 Shaft Station and Loading Pocket areas. Concern at the time was understandable since the No.4 Shaft downcasts 300,000 c.f.m., no blasting had occurred anywhere near the 3650 Level, and yet there was blasting gas reported at the shaft.

With the injection of stench gas (ethyl mercaptan), the mine was evacuated with the exception of the three miners on the 3850 Level. Mine rescue teams were assembled and sent to recover the three workers.

SULPHIDE DUST EXPLOSIONS

A dust explosion occurs when a cloud of combustible dust at a concentration within the explosible range, is exposed to an external source of ignition with sufficient energy to ignite the dust.

W.J. Montgomery, Department of Mines and Technical Surveys, Ottawa, stated in his report of June 1961. - " A Sulphide dust explosion is an extremely rapid oxidation. Sulphide ores are inorganic, hence there are no combustible volatile constituents. The ease of oxidation of metallic sulphides gives the explosive characteristics." This rapid oxidation is shown by the typical reactions:

$3\ FeS_2 + 8O_2 = Fe_3O_4 + 6SO_2$ (Magnetite)

$4\ FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2$ (Hematite)

The resultant dust is red suggesting the presence of hematite or black indicating magnetite. In all cases sulphur dioxide gas is produced.

Associated with and in response to the explosion, are two phenomenons, "pressure wave" and."flame front". Both vary in degrees of intensity dependant on conditions. The flame front exists only while fuel is available, i.e. dust produced or aroused from the intial blast, secondary explosion or on the walls, back and floor of the surrounding area. The pressure wave is a direct result of the secondary dust explosion, which travels until it's energy is dissipated into the mine workings. One can visualize that the pressure wave causes the damage to vent doors, construction areas, can move mine cars, damage installations etc. and at the same time disturb additional fuel (dust) for the flame front progressing behind. Meanwhile it will also carry initially produced sulphur dioxide gas to the surrounding workings.

The flame front however will continue to produce sulphur dioxide until insufficient dust is available to maintain it.

The phenomenon therefore creates three major problems for underground operations:-

1. The initial explosion can be of a force to endanger both personnel and equipment.
2. The flame front with its' intense heat may endanger men or materials as well as start underground fires upon reaching combustible areas.
3. The sulphur dioxide gas produced may be in quantities and concentrations injurious to workers, and can be distributed thoughout the underground workings by the initial explosion and pressure wave itself.

Historically since discovery of the Geco orebody and mining began, small sulphur dioxide occurrences have occasionally been experienced, usually after secondary blasting in scrams or boxholes, or in drop raise blasting. The few occurrences were relatively minor and were dealt with in a fashion similar to all underground blasts producing blasting gases whether NO2, NH4OH, CO, CO2, smoke or otherwise.

Possibly SO2 occurrences may have been more numerous than acknowledged, however, the systematic clearing of blasting smoke, gases, etc. by forced ventilation was simply a common occurrence, whether the gas was NO2, NH4OH, CO, CO2, smoke or SO2.

As in any mine, small development blasts, secondary blasts, etc. are loaded, cleared, guarded, fired and re-entry allowed after an allotted time and/or gases are cleared. The occasional odour of SO2 was dealt with as any gas, that is retreat to fresh air and await time for clearing.

Perhaps the following Table 4 of typical mining areas serves to indicate why sulphide dust explosions at Geco seldom occur.

STOPE	PERCENT SULPHUR
2-29	24.5 % S
4-24	29.1
6-14	6.2
18-36	21.0
18-42	19.5
26-46	28.3
26-52	12.8
28-56	4.5

TABLE 4 TYPICAL STOPE SULPHUR CONTENT

Sulphide dust explosions require specific conditions to occur:-

1. Fuel
2. Oxygen
3. Ignition
4. Confined Space (container)

FUEL

All sulphide ore deposits contain fuel or sulphide dust. Mr. K.G. Wheeland, Noranda Research, from laboratory testing in 1980 stated that sulphide dust explosions generally adhere to the following parameters, given optimum conditions.

Less than 23% S - explosion unlikely
23% to 29% S - explosion possible
+29% S - explosion probable

In Geco's instance the 2346 void blast contained 31.4% sulphur as shown in Table 3, however overall sulphur content in the 2646 Block averaged 28.3%.

The fuel itself must be in particle form, the smaller the dust particle the more prone to becoming airborne, reacting with oxygen and oxidizing and burning.

There are four main ways in which dust clouds are created:-

1. Air blast from initial holes disturb dust laying on roof, walls and floor.
2. Impact of blasted rock on walls and floor.
3. Detonation ejects fine dust into space around holes.
4. Drill cuttings containing sulphide are used as stemming or decking.

In the Geco event although the area had been washed prior to the blast, most probably all four of the above contributed in part to the formation of the cloud.

IGNITION

To occur, the event requires an external ignition source coupled with a supersaturated dust environment. In Geco's case (as shown in Table 5) the slot raise cut immediately above the void blast was fired as late as 1300 ms behind the first longhole detonation. This provided the ignition source examples of which include:-

a) hot explosion gases

b) burning particles of undetonated explosives

c) misfires

d) burning particles of pyrite

e) delayed detonation

Any of these five could have contributed to Geco's ignition, however, most probably the explosives detonating in the slot raise cut provided the source.

DELAY NO.	DELAY TIME	DELAY FROM FIRST SHOT
	VOID BLAST	
4	100 ms	0 ms
5	160	60
6	200	120
19	1025	925
	SLOT RAISE BLAST	
1	490 ms	390 ms
2	790	890
3	1090	990
4	1400	1300

TABLE 5 2346 VOID BLAST DELAYS

EXPLOSION CONTAINER

VRM blasthole stopes provide extremely optimum conditions for sulphide dust explosions. Similarly drop raises, which are in effect small VRM stopes can also be viewed as optimum areas, since a container is available in which the explosion can occur. In this confined space, dust is contained, oxygen provided, and with ignition available an excellent location for a dust explosion to occur. Figures 9 through 11 show pictorially the way in which a container was created in Geco's case and an optimum location formed for the blast to occur.

In reviewing these illustrations closely, one can envisage that the explosion area resembled that of a piston engine. The drop raise cut provided the spark or ignition, but only after sufficient delays moved the muck from the longhole blast, created a chamber or container and created sufficient dust providing the fuel.

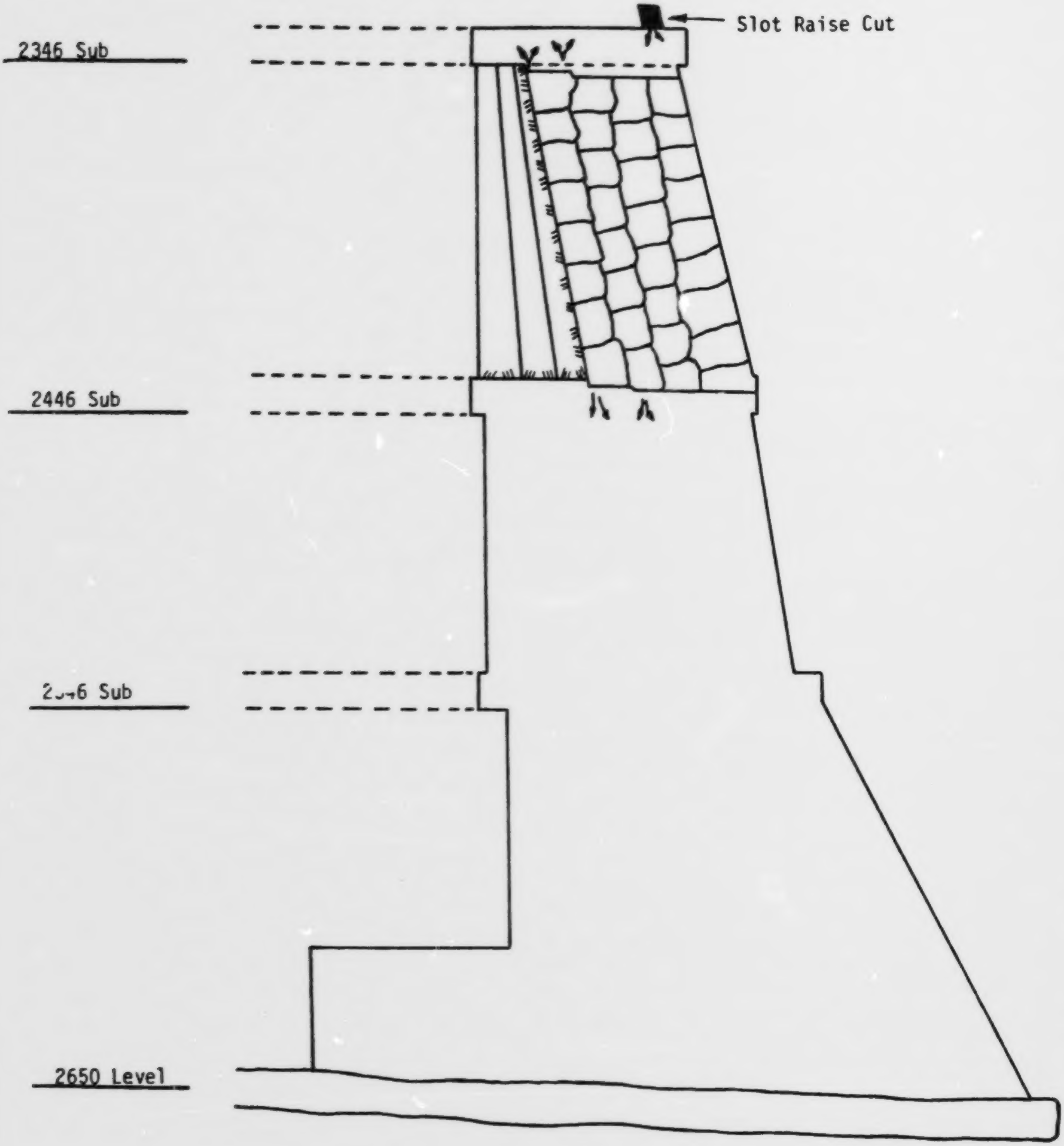

Slot Raise Cut
2346 Sub
2446 Sub
2546 Sub
2650 Level

FIGURE 9 Initial Movement of Muck During Void Blast

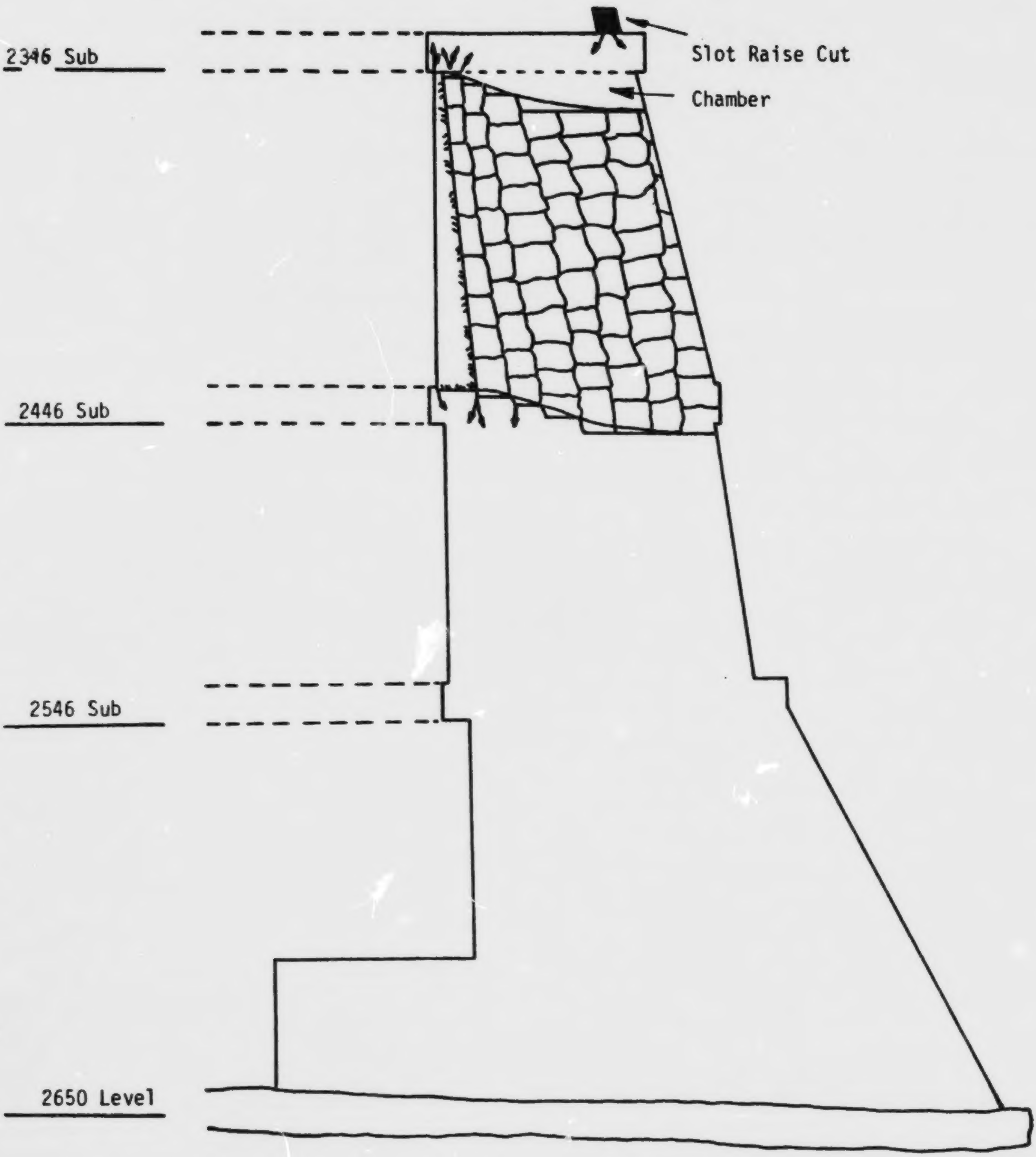

2346 Sub
Slot Raise Cut
Chamber
2446 Sub
2546 Sub
2650 Level

FIGURE 10 Muck Falling Creating Chamber Above

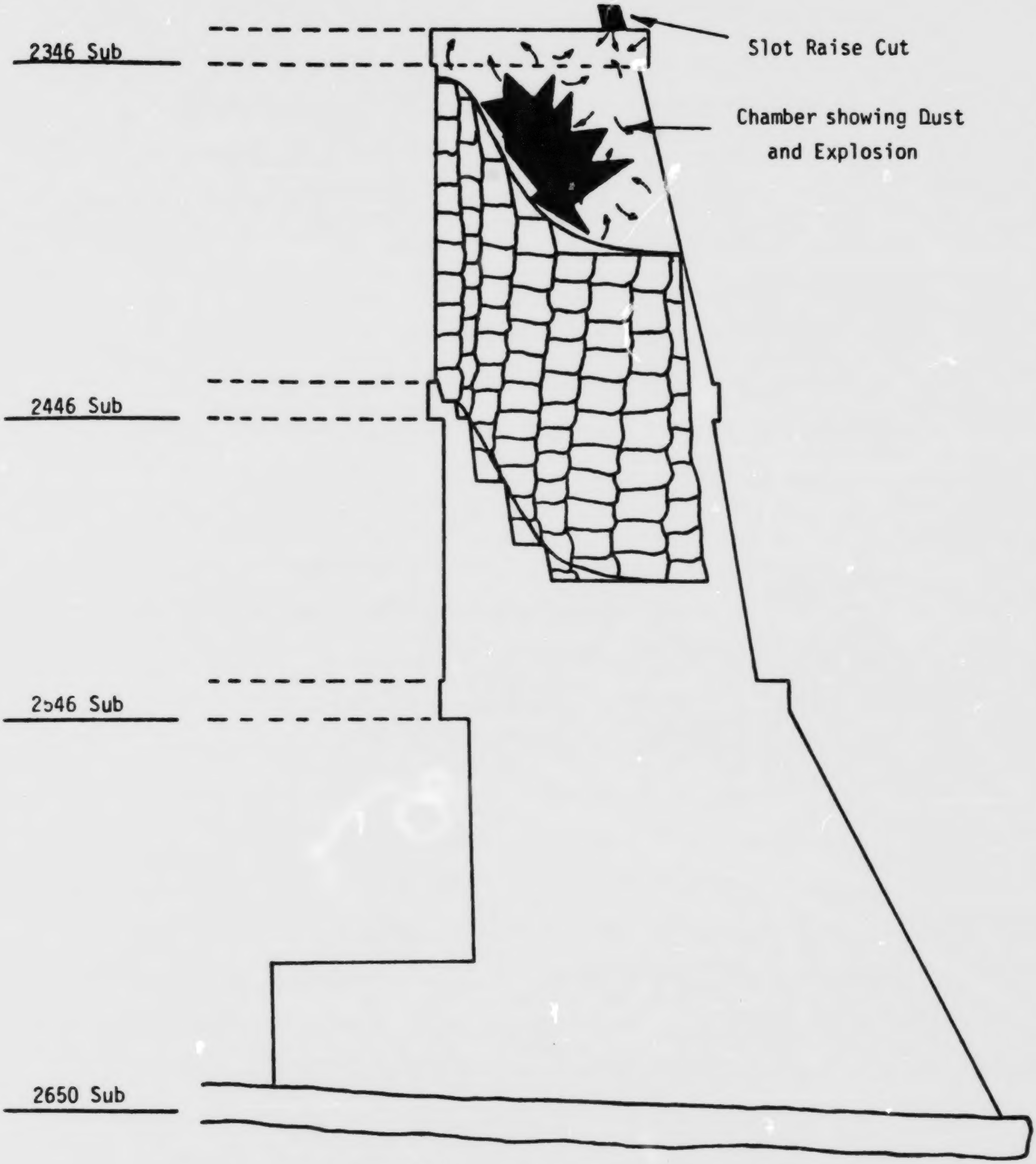

2346 Sub
Slot Raise Cut
Chamber showing Dust and Explosion
2446 Sub
2546 Sub
2650 Sub

FIGURE 11 Chamber Containing Dust

LABORATORY INVESTIGATION

Following the incident, samples of typical 2346 unaltered ore, as well as samples of dust collected on the 2450 and 2650 Levels in the 2646 vicinity were forwarded to Noranda Research as well as Dr.R.J. Enright of the University of Sydney, Australia. Dr. Enright in his report of February 24, 1986, concluded that through laboratory analysis upwards of 80% of the resultant dust from the explosion was found to be magnetic. Under a microscope, spheres and cenospheres (hollow spheres) were present typical of magnetite produced by exploding pyrite, confirming that a sulphide dust explosion had occurred.

Dr. Enright further concluded that the dust was explosive over a wide range of concentrations. This was arrived at from tests at the University of Australia on the 2646 Pillar ore. Tests confirmed that under laboratory conditions 500 g/m3 (0.5 oz/cf.) and possibly as little as 200 g/m3 (0.2 oz/cf.) dust concentration was explosive.

D. Doutre and K.G. Wheeland, Noranda Research Centre, reported from experimentation in July 1980 that "Dust concentrations as low as 0.5 oz/cu.ft. (500 g/m3) are sufficient to propagate a flame front. This corresponds to less than 2 oz/sq.ft. along the surfaces of an 11 x 17 ft heading."

ALLEVIATION - PREVENTION

Excellent work has been performed under laboratory conditions on methods of prevention of sulphide dust explosions. One would hope there is a simple solution, however, we know this is far from occurring.

Removal of any one of the four combined primary causes will alleviate the problem.

FUEL

Fuel is difficult to remove since blasting the deposit is the root of the problem. However, the addition of inert substances, limestone, water, etc. act as a diluent, water also at times being referred to as a "heat sink", which in some cases can reduce the risk.

Additives are costly. No real practical measure can be ascertained to determine the amount of dust which will be generated, or which may be in the surrounding area. Neither can the content of the sulphide dust or fuel be measured. Hence no practical way can be determined to measure beforehand the amount of inert substance required to suppress the phenomenon. Also, the addition of a further blasting commodity such as limestone in amounts to suppress explosions may not be practical from a cost point of view except in smaller development or secondary type blasting.

The washing of walls, backs, etc. prior to blasting is probably the most effective, and least costly method of reducing the risk of flame propogation from fuel stored prior to the blast. The use of water sprays triggered to the blast in outside areas further will supress the flame front should it reach this location. The use of water stemming or water sprays in the location of the blast will aid to suppress the heat and ignition sources during the blast, however the amount required in larger blasts is unknown and cannot be determined beforehand due to the many variables, i.e. heat, explosives, sulphur content, dust generated, dust nearby, etc.

In addition Dr. Enright cautions the use of water stating, "It is possible for hydrogen sulphide to be produced from wet pyritic dust and hydrogen sulphide is more toxic than carbon monoxide." Hydrogen sulphide also is a combustible gas.

External fuel (that dust on hand prior to blasting) can and should be eliminated. The main problem exists with the dust or fuel generated during blasting. It is almost an impossible task to predict the amount of dust which will be generated, which will in turn be ignited. However, there are ways to reduce it, including a look at hole size, pattern, muck sizing (i.e. the smaller the muck size = the larger the combined particle surface area = increased dust), delaying techniques, powder type, etc. No magic formula is available. In planning stages it may be worthwhile to consider designing blasts differently to include smaller portions of lower grades or disseminated zones thereby diluting the pyritic concentration with an insitu semi inert substance.

OXYGEN

No practical way of eliminating oxygen in a blast area seems likely, however, the introduction of large volumes of ventilating air into the area, or the use of air with water sprays will only aggravate the situation. No doubt the design of a blast of short duration which excludes oxygen is desirable.

CONTAINER

On December 21, 1985 at 11:55 p.m. the "final blast" in this 2646 Pillar and the largest in Geco's history, was fired containing 375,000 lbs of explosives and breaking 809,000 tons. The 2646 X.C Vent door was placed in a position similar to the night of October 10, 1985. After the blast an investigation revealed that no sulphur dioxide could be noted nor was there evidence of a secondary explosion and as well the vent door remained as normal. This blast, with an estimated 20% void beforehand required the total void to encompass the swell from the broken muck. Hence no container was available in which a secondary dust explosion could occur.

This indicates that minimizing the void area i.e. maintaining sufficient muck elevation whether VRM or conventional, may be advantageous. In other words the void opening should be of a size to accept the broken muck swell only. This aids in three ways. Less surface area of the container is available storing settled dust and as well less oxygen and volume is available for the secondary explosion to occur.

IGNITION

From the Geco 2646 experience the primary recommendation would be to prohibit all secondary nearby blasting occurring simultaneously with a primary blast, i.e. drop raises, sand blasts, hangups, secondary blasts, etc. In other words ignition should not be provided in a nearby location for dust disturbed or created elsewhere. As well, by minimizing the blast duration, sufficient fuel is not available prior to the last shot firing (excluding misfires) to propogate the event. Coal mines as do some metaliferous operations suggest a maximum blast duration of 200 ms., however this is most difficult taking into consideration the many advantages of delayed sequential blasting.

Reducing ignition temperatures through explosives products used is an area virtually untouched. Although most explosives and accessories probably will propogate a dust explosion, varying explosion state temperatures, degrees of destruction of the product itself, make some products more desirable from a sulphide dust explosion than others. Little work has been done in this regard.

At Geco, in addition to the methods previously described to reduce risk, all mining locations are detailed for sulphur content, and probability of occurrence. As well, gas checks are taken after longhole blasts.

CONCLUSIONS

Sulphide dust explosions may be controlled to varying degrees however at this time they cannot be eliminated.

Four distinct approaches should be investigated by concerned underground sulphide operations:-

A)Know the Problem- this includes differentiating zones of sulphur occurrences, and the degree at which it occurs.

B)Education- Educate all concerned including geological, engineering and operating personnel to the occurrence and the hazards of sulphide dust explosions and the resultant effects.

C)Control Prior to Blasting- Through the use of techniques available as suggested beforehand or as developed locally including the eliminaton of ignition, fuel, oxygen and container, the occurrence may be kept in check.

D)Control After Blasting- Operations should be aware that upon return to the underground area, there may be no evidence of the occurrence of an explosion, that the incident itself or the ventilation system may have transported sulphur dioxide gas throughout the mine, hence caution should be exercised. Complacency can be the biggest single problem in this regard.

Geco has set guidelines for the safe mining of the ore body with respect to sulphide dust explosions and resultant forces.

In addition Geco along with its' parent Noranda has and will continue to work with private and government bodies to more readily define the problem and outline solutions or preventative measures.

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3. Montgomery, W.J., - A Comparison of the Explosibility Characteristics of Some Canadian Coal Mine, Base Metal Mine and Industrial Dusts, June 1961.

SHERRITT GORDON MINES LIMITED
LEAF RAPIDS, MANITOBA

MR. LUCIEN NELS, VENTILATION ENGINEER

sherritt

CONTROL OF SULPHIDE DUST EXPLOSIONS AT RUTTAN

L. D. NEL
SENIOR VENTILATION ENGINEER
RUTTAN OPERATIONS
SHERRITT GORDON MINES LIMITED
LEAF RAPIDS, MANITOBA
OCTOBER, 1986

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ABSTRACT

Sherritt Gordon Mines Limited, Ruttan Operations is a copper/zinc mine in northern Manitoba that has been in operation since 1973 - first as an open pit operation and later, in 1979, as an underground mine.

The hazards associated with the mining of massive sulphide deposits are well known, but little understood. During Ruttan's existance as an underground mine, mine personnel have become accutely aware of the dangers associated with secondary sulphide dust explosions and the generation of sulphur dioxide.

The paper is a case study of the development of a practical approach to the prevention and prediction of "sulphides" at Ruttan. Emphasis is placed on prevention, explosion damage and predictability of these occurrences.

RÉSUMÉ

La mine Ruttan de la Sherritt Gordon Mines Limited est une mine de cuivre et de zinc située dans le nord du Manitoba. Elle est exploitée depuis 1973; d'abord mine à ciel ouvert, elle est depuis 1979 une mine souterraine.

Les risques associés à l'exploitation de gisements de sulfures massifs sont bien connus, mais peu compris. Depuis que la mine Ruttan est souterraine, le personnel minier a pris vivement conscience des dangers associés aux coups de poussières sulfurées secondaires et à la production de dioxyde de soufre.

Le présent rapport est une étude de cas de l'élaboration d'une méthode pratique de prévention et de prévision de la concentration des sulfures à la mine Ruttan. Elle porte en particulier sur la prévention, l'évaluation des dégats des coups de poussières et la prévision de ces derniers.

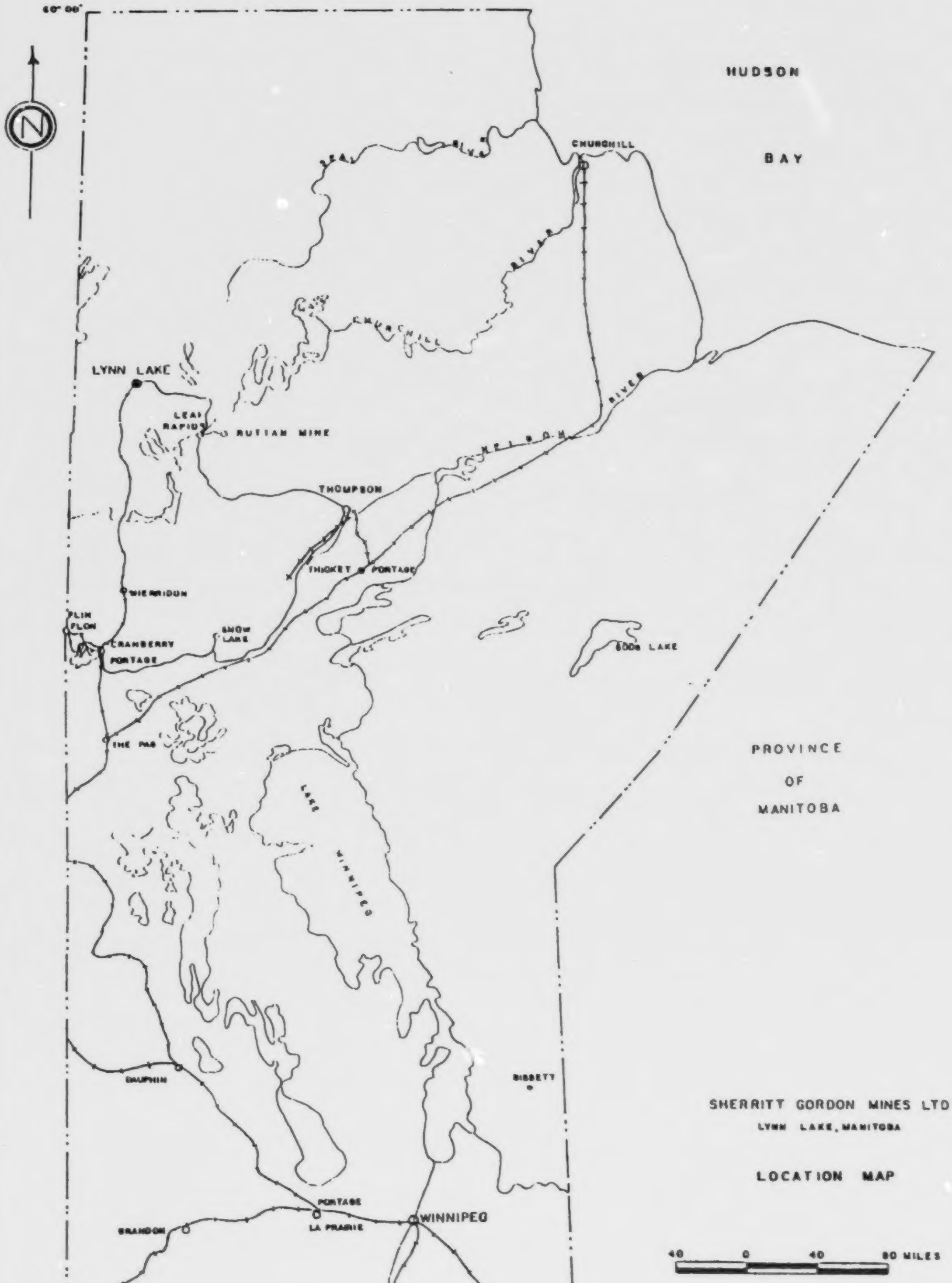
INTRODUCTION

The dangers associated with sulphide dust explosions and the generation of sulphur dioxide are well known to the Canadian Mining Industry. Sulphide dust explosions and sulphur dioxide generation has been of concern to mine operators, and is now receiving more attention. This symposium attests to the fact that the industry is becomming increasingly aware of the real threat posed by sulphide dusts, not only to the health and safety of mine personnel, but also to the costs associated with the operation.

If we were able to determine the total cost associated with sulphide dust explosions, additional research into this problem would be more widely supported in the Mining Industry.

At Ruttan the cost incurred as a result of sulphide blast have been high in terms of production loss and property damage. Inhalation of sulphur dioxide fumes by our personnel has required first aid treatment and referrals to our local hospital.

Precautionary measures have been developed at Ruttan over the past 7 to 8 years to prevent and minimize the effects of these sulphide dust explosions. However, incidents do still occur at an unacceptable level and our objective should now be to eliminate the basic causes of sulphide dust explosions.


60° 00'
N
HUDSON
BAY
SEAL RIVER
CHURCHILL
CHURCHILL
RIVER
LYNN LAKE
LEAF RAPIDS
RUTTAN MINE
NELSON RIVER
THOMPSON
THICKET PORTAGE
SHERRIDON
FLIN FLON
CRANBERRY PORTAGE
SNOW LAKE
GODS LAKE
THE PAS
LAKE WINNIPEG
PROVINCE
OF
MANITOBA
BISSETT
DAUPHIN
PORTAGE LA PRAIRIE
WINNIPEG
BRANDON
40 0 40 80 MILES

SHERRITT GORDON MINES LTD

LYNN LAKE, MANITOBA

LOCATION MAP

I/2.5

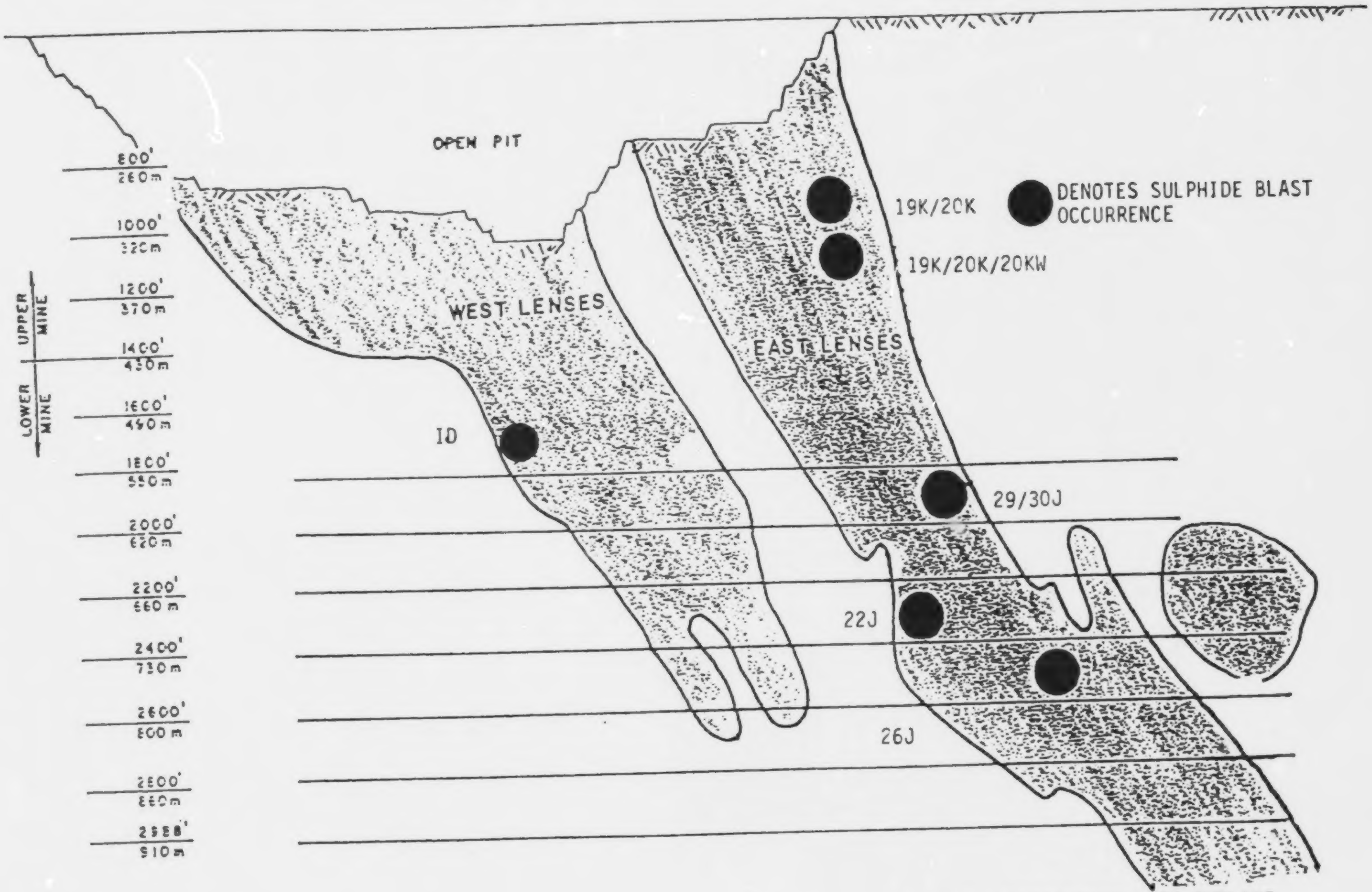
FIGURE 1

RUTTAN'S GEOLOGY

The Ruttan Mine Site, owned and operated by Sherritt Gordon Mines Limited is a copper/zinc mine located in northern Manitoba. The 6,000 tonne per day mine has been an underground operation since 1979 and has recently been deepened to 860 meters below surface.

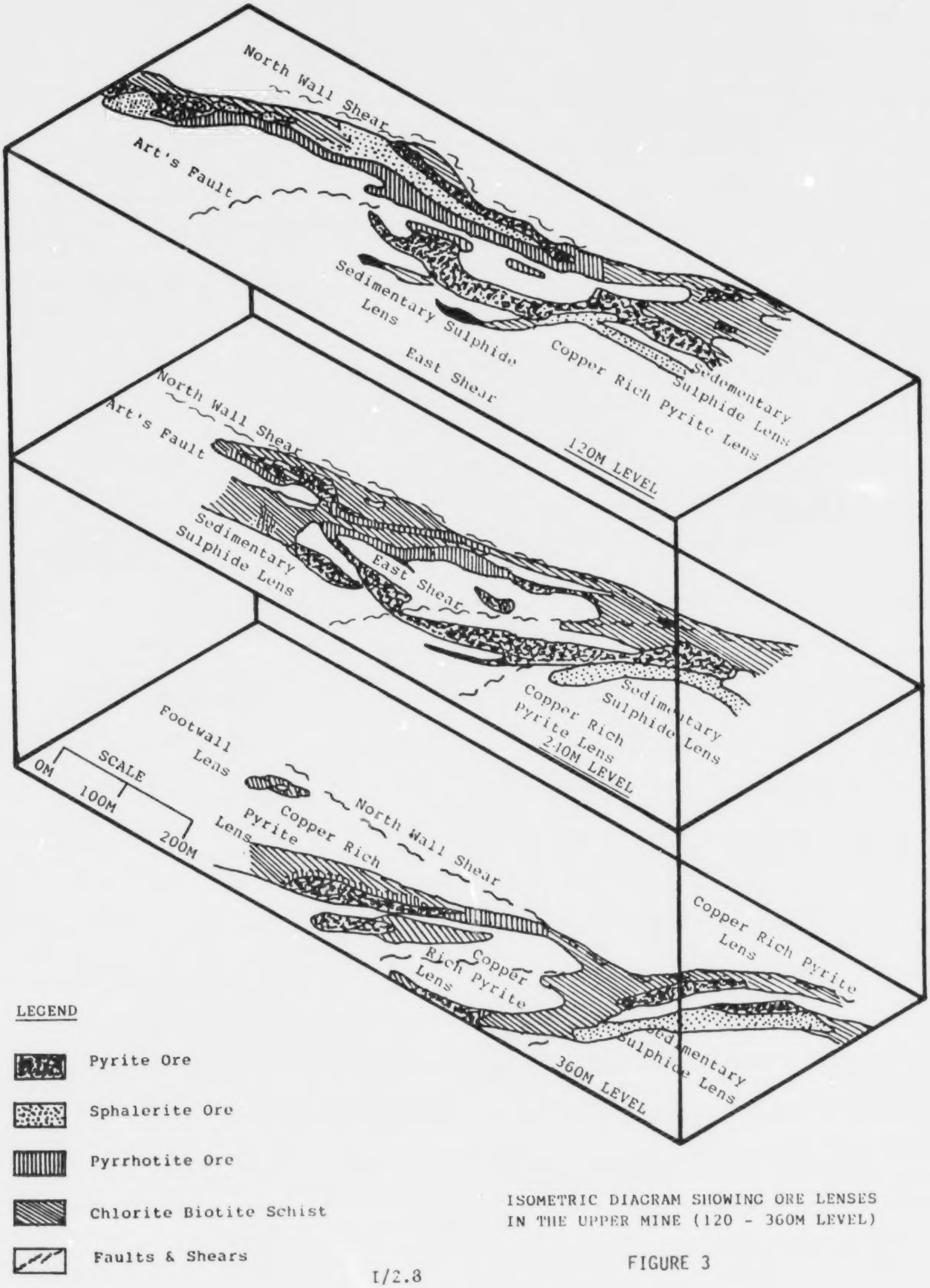
Ruttan's ore zone occurs generally conformable within a series of metamorphosed intermediate volcanics and volcanic derived sediments. The ore body is made up of numerous en echelon massive and semi-massive sulphide lenses. Minerals within the ore lenses include pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena in varying propostions, while gangue material is mainly composed of quartz, feldspar, chlorite, biotite, sericite, staurolite and garnet.

Figure 2 depicts the longitudinal ore lens arrangement of the mine indicating the areas where sulphide problems have been encountered. The ore body consists of two main lenses, the west lens and the east lens. Both of these lenses are further classified into sedimentary sulphide lenses, copper rich pyrite lenses and a footwall lens which are shown in Figure 3.


OPEN PIT
800'
260m
1000'
320m
1200'
370m
1400'
430m
1600'
490m
1800'
550m
2000'
620m
2200'
660m
2400'
730m
2600'
800m
2800'
860m
2988'
910m
UPPER MINE
LOWER MINE
WEST LENSES
EAST LENSES
ID
19K/20K
19K/20K/20KW
29/30J
22J
26J
● DENOTES SULPHIDE BLAST OCCURRENCE

RUTTAN'S LONGITUDINAL ORE OUTLINE

FIGURE 2


North Wall Shear
Art's Fault
Sedimentary Sulphide Lens
East Shear
Copper Rich Pyrite Lens
Sedementary Sulphide Lens
120M LEVEL
North Wall Shear
Art's Fault
Sedimentary Sulphide Lens
East Shear
Copper Rich Pyrite Lens
Sedimentary Sulphide Lens
240M LEVEL
Footwall Lens
SCALE
0M
100M
200M
Copper Rich Pyrite Lens
North Wall Shear
Copper Rich Pyrite Lens
Copper Rich Pyrite Lens
Sedimentary Sulphide Lens
360M LEVEL
LEGEND
Pyrite Ore
Sphalerite Ore
Pyrrhotite Ore
Chlorite Biotite Schist
Faults & Shears

ISOMETRIC DIAGRAM SHOWING ORE LENSES
IN THE UPPER MINE (120 - 360M LEVEL)

FIGURE 3

Initially it was thought that the secondary sulphide ignitions were restricted to the east lenses, however, they have also been experienced in the intermediate zone between the east and west lenses known as the 'H' zone. More recently we have experienced similar problems in the 'D' zone which form part of the west lenses shown in Figure 2. The mineralogy of the 'D' zones, however, differs from that of the accepted norm for the west lenses and displays some unique similarities to that of the east lenses. All areas prone to sulphide blasts and sulphur dioxide generation, with the exception of the 'D' and 'H' zones previously mentioned, are situated within the east lenses which exhibit a higher pyrite content than the west lenses.

The east lenses are relatively homogenous mineralogically and are significantly different to the west lenses. One of the most prominant differences, in the context of this paper, being the crystallography of the pyrites. The sulphur content of these pyrites throughout the mine ore body have a comparatively narrow spread ranging from 43.4% to 53.4%. The recrystalized pyrite of the east lens is characterized by a larger grain size and weaker molecular bonding which is considered significant in that the crystals are more readily fragmented by blasting into fine airbourne particulate matter. The abundance of pyrite, which can reach 90-100% in the ore horizon of the east lenses, the sulphur content of the pyrite and the friability of the pyrite crystals, we believe are the major contributing factors to the creation of explosive atmospheres at Ruttan.

A study conducted by Haverslew, which concentrated on the genesis of the Ruttan ore body, indicates that the sulphur content of our pyrrhotite ranges between 33% and 34.46% by weight and therefore has not been considered in this hypothesis.

Furthermore, pyrrhotite distribution is concentrated in the west lenses which historically have not experienced sulphide dust problems.or hot muck.

MINING METHOD AND BLASTING

Two variations of blasthole open stoping are used to extract Ruttan's ore. This is followed by delayed backfill using both dry rockfill and hydraulically placed classified tailings. These two variations include 4 1/2" diameter blastholes drilled in most cases to remove an undercut and/or overcut, the 6 1/2" diameter holes are drilled, usually parrallel to facilitate the main production blasting and ore removal from the stope.

Figure 4 is a diagram of a typical stope. Once the stope outline is defined, a 5' diameter raise is bored which forms the initial free face for the slot blasting. The slot is then blasted into this void and finally the remainder of the stope is mined using a sequential vertical slicing technique. Broken ore is mucked from the drawpoints on the lower level of the stope using diesel powered load haul dump units. Using this mining method, the stope is an open system, always having an opening to the top of the stope and thus not confining sulphide dust. The container effect described by Byberg (1985) is therefore not a factor in our secondary sulphide ignitions.

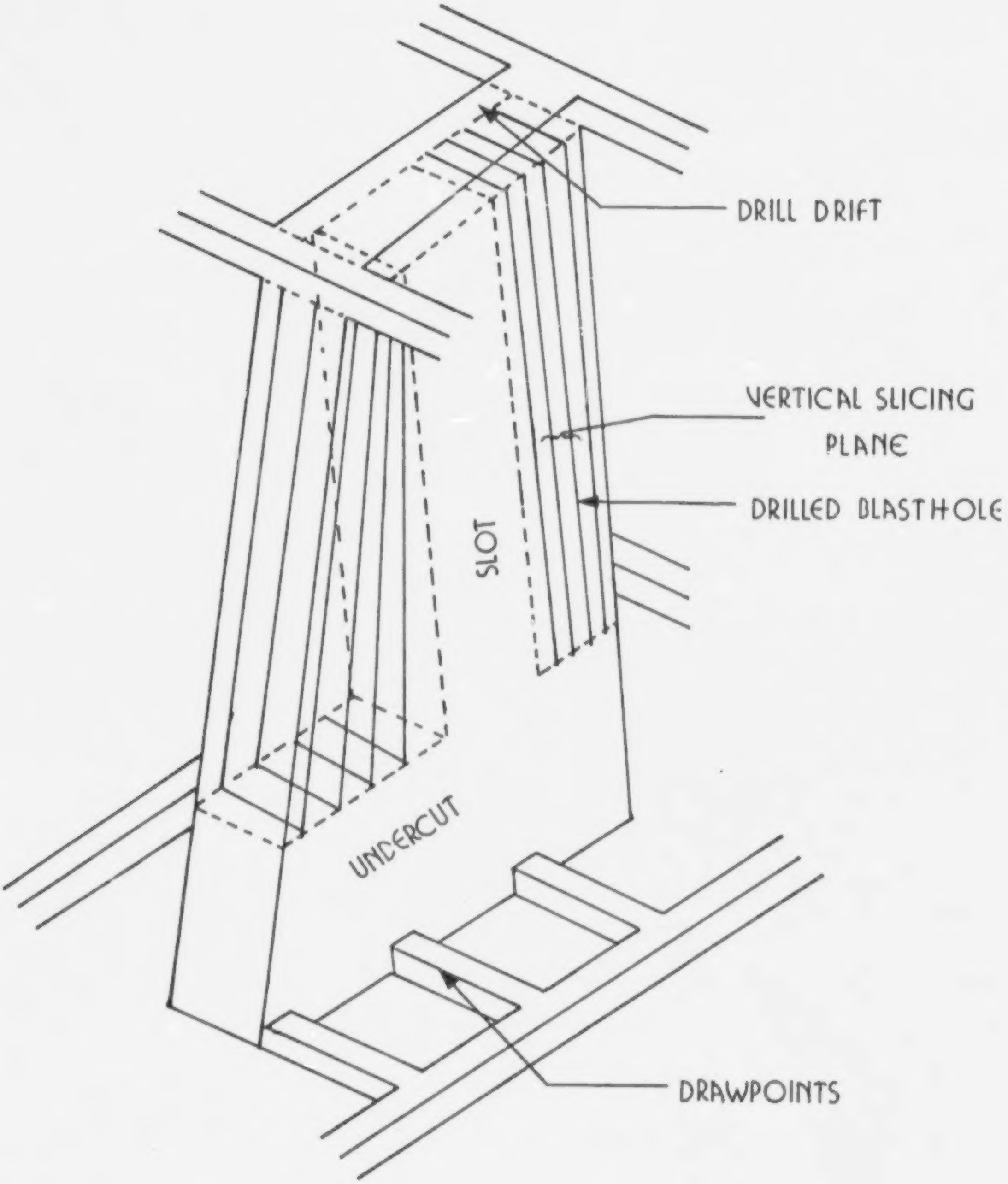

DRILL DRIFT
VERTICAL SLICING PLANE
DRILLED BLASTHOLE
SLOT
UNDERCUT
DRAWPOINTS

FIGURE 4

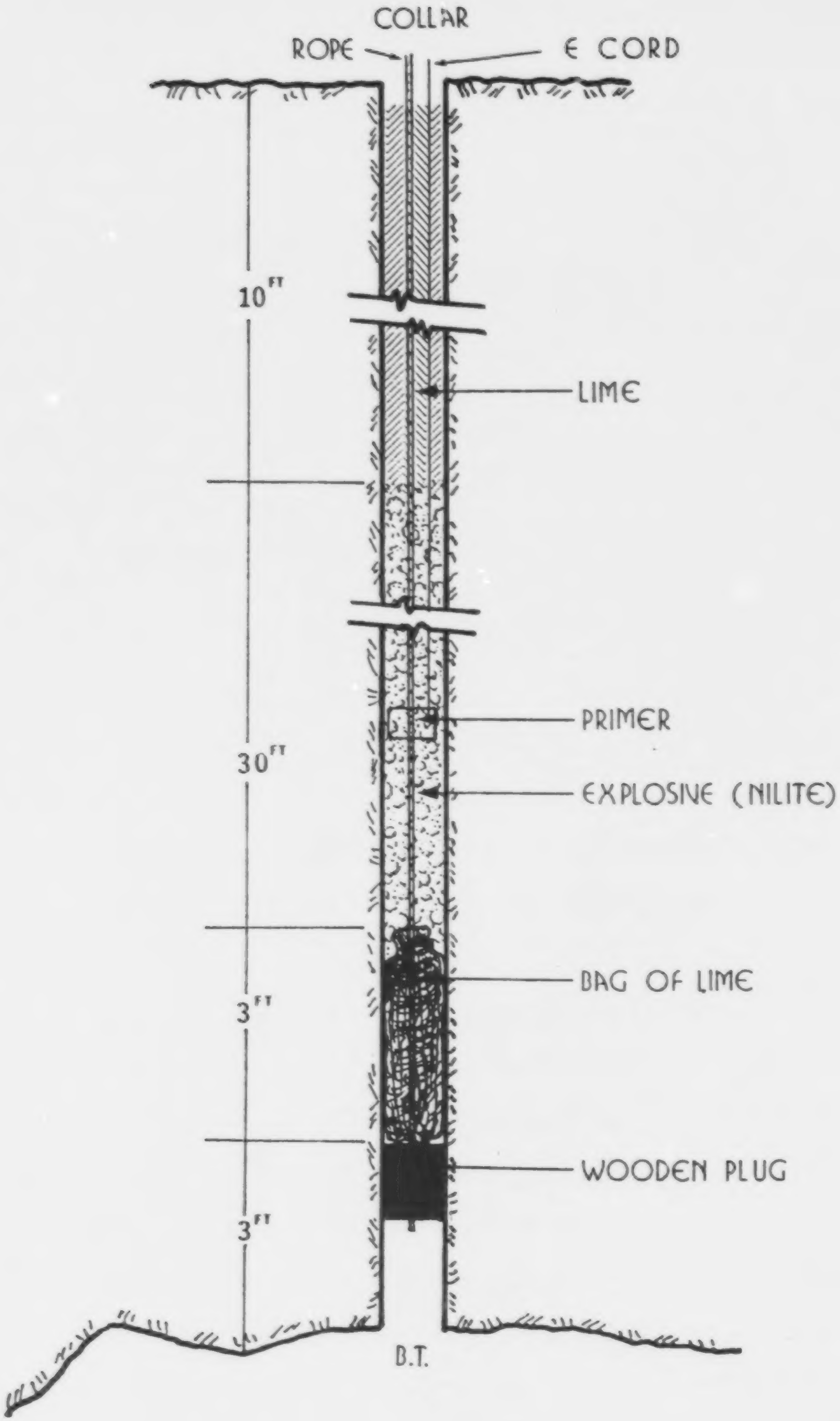
STOPE

This could partially explain why the secondary sulphide dust explosions experienced at Ruttan are not considered to be as violent as those experienced at some other mines.

Explosives used in both production, primary and secondary blasting, and development blasting are of the non-alluminized variety. Figure 5 shows a typical arrangement for a loaded production blasthole. Agricultural lime is used as stemming in all cases and also to separate the decks of explosives in the hole. All primary blasting is restricted to the shift change when the mine is clear of personnel.

The ventilation system's general flow pattern is from east to west and footwall to hangingwall. The main objective of creating these flow patterns is to clear the post secondary ignition sulphur dioxide away from the main access routes and maintain a clean air flow in towards the affected production area. Exhaust vent raises are located in the hangingwall and intakes in the footwall.

The Lower Mine ventilation system, however, has not yet been completed and there are areas in the development stage which are still reliant on auxilliary systems. During a secondary sulphide dust explosion these auxilliary systems are usually rendered ineffective by damage sustained, and result in pockets of SO_2 lingering in high concentrations which slowly bleed into the main through ventilation path, causing prolonged production delays. In some instances, sulphide dust explosions have damaged critical ventilation


COLLAR
ROPE
E CORD
10 FT
LIME
30 FT
PRIMER
EXPLOSIVE (NILITE)
3 FT
BAG OF LIME
WOODEN PLUG
3 FT
B.T.

TYP. BLASTHOLE

FIGURE 5

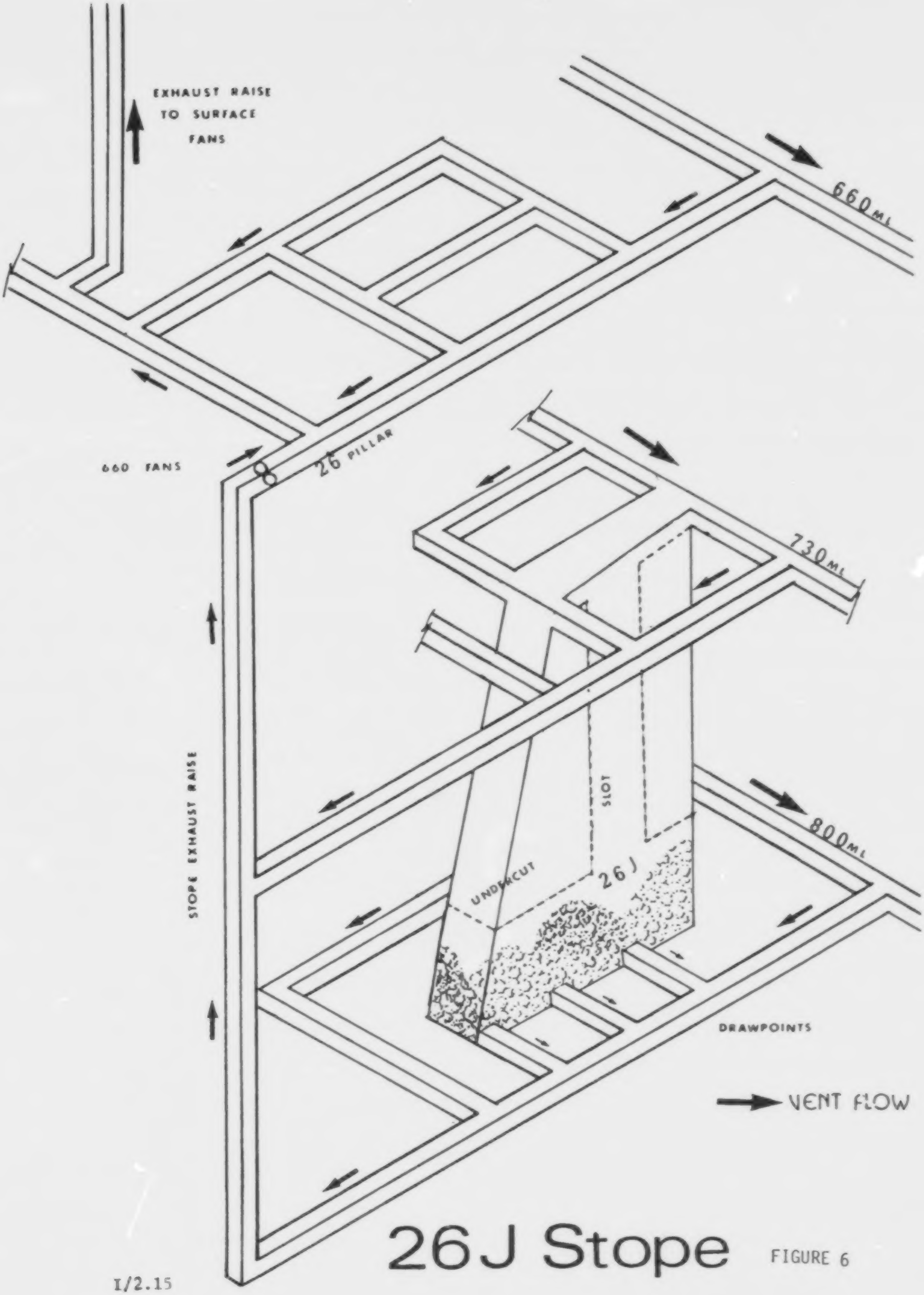
installations which have resulted in major airflow reversals and enveloped the sites where damage has occurred thus hampering rehabilitation.

THE 800-26J INCIDENT

800-26J stope, situated within the Lower Mine's predominant east lenses, is within a zinc rich pyrite area. On July 22, 1986, at 12:00 midnight, the second last stope blast was initiated with some dramatic after effects. Figure 6 is a diagram of the stope with its adjacent drifts. The ventilation raise shown serves this general area amd discharges the exhaust on 660 metre level into an exhaust to surface by means of two 36" fans in parallel.

The primary production blast initiated a secondary dust explosion which had sufficient force to lift the fans from their moorings, approximately 140 metres above the area, and propel them down the 660-26 pillar crosscut for approximately twenty meters.

The first indication of the problem became apparent when the man cage returned to surface after its post blast trial run with a 50 foot length of 42" diameter flexible ventilation tubing. The vent tubing had, prior to the blast, been delivered to the 730 shaft station. During the subsequent shaft inspection, two more lengths of vent tubing were found in the shaft just below 490 metre level, some 240 metres above the 730 shaft station. In addition to this, a regulator in the 370 east exhaust complex


EXHAUST RAISE
TO SURFACE
FANS
660ML
660 FANS
26 PILLAR
730ML
SLOT
800ML
UNDERCUT
26J
DRAWPOINTS
STOPE EXHAUST RAISE
VENT FLOW

26J Stope FIGURE 6

had also been damaged. With these controls gone there was no means of ventilating the lower section of the mine. The incident resulted in a production delay of five shifts for the Lower Mine which consitutes many of our main production areas.

Although this incident is considered the worst to date from a production point of view, numerous other similar incidents have caused equipment damage, personal injury in the form of sulphur dioxide inhalation, and production delays.

RESEARCH RELATING TO RUTTAN

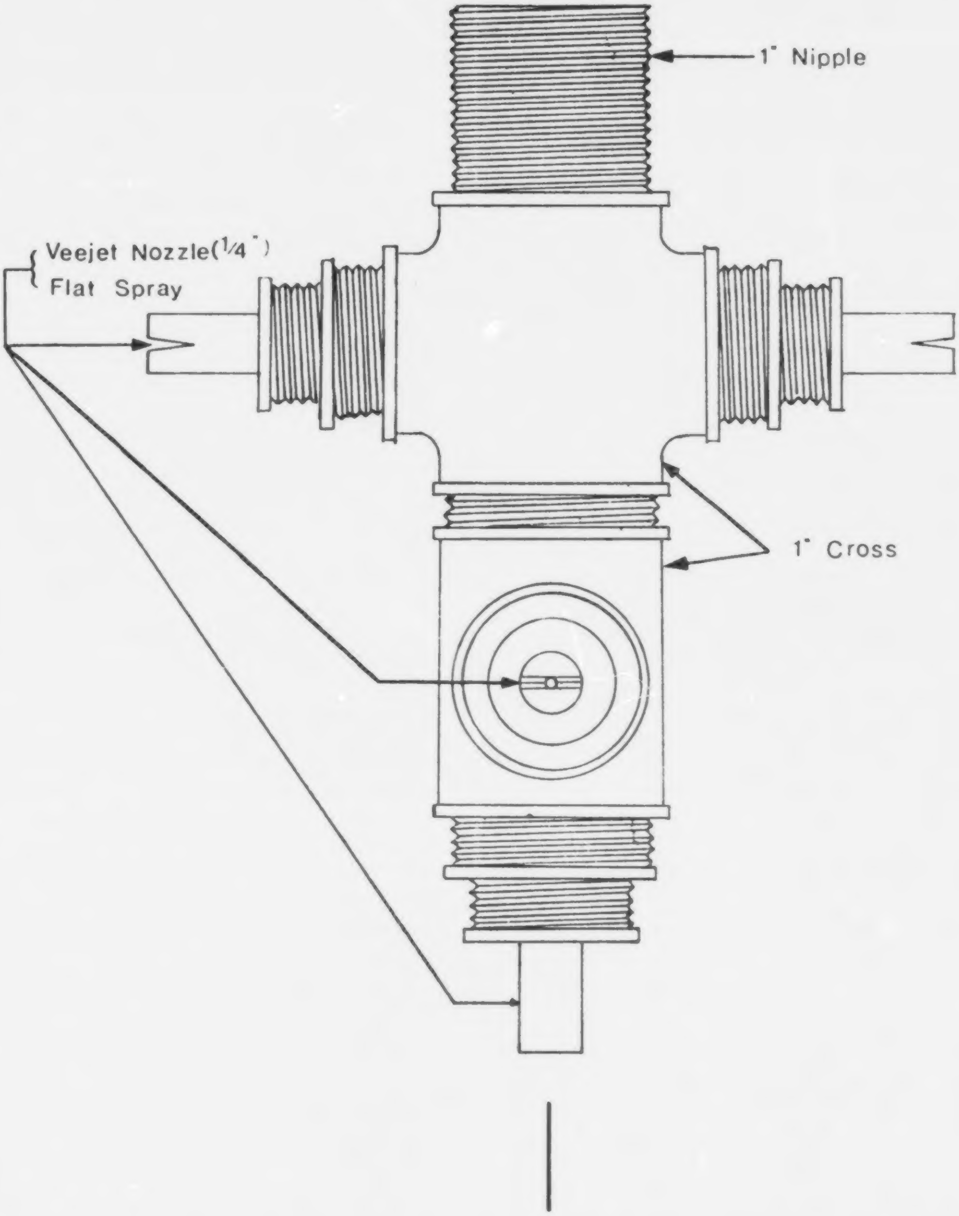
Little formal research concerning the sulphide dust problem at Ruttan has been done in the past. The research is very limited and has concentrated on the use of explosives and their exhaust temperatures as a method of preventing sulphide blasts. Information gleaned from various unrelated geological studies has also proved useful to some extent.

At present insufficient reliable data is available from these studies to enable the sulphide occurrences to be predicted with any degree of certainty. The only prediction that can be made with any confidence is that all blasting activities within the east lens ore zone are prone to secondary sulphide ignitions. Another prediction along the same lines is that as the mining activity progresses deeper, the sulphide occurrence frequency will increase. The University of British Columbia is presently drafting a proposal to research the problem at Ruttan. The study will be directed at developing a long term control program for Ruttan and will include the following:

1. Provide an improved information base for sulphide dust ignitions.
2. Study the nature and sources of heat.
3. Evaluate methods used to prevent sulphide dust explosions.
4. Predict explosive conditions.
5. Quantify the costs involved with explosion damage and production loss.
6. Develop rapid tests to determine the relative hazards of pyritic ores.
7. Establish, if possible, a correlation between explosibility and underground location, and examine the explosibility as related to the ore body exposed area.

PRECAUTIONS TAKEN TO MINIMIZE THE DANGERS OF SULPHIDE BLASTS

The precautions discussed are standard practice at Ruttan and are believed to assist in the prevention of sulphide explosions. The primary consideration in developing these precautions was to prevent the creation of an explosive atmosphere. As previously mentioned, the use of alluminized blasting agents is prohibited at the mine because of the excessively high temperatures generated by these products. The lower mechanical energy producted by a non-alluminized explosive is considered an acceptable compromise when considering the potential devastation of a secondary dust explosion. To futher reduce the explosive exhaust gas temperatures and to assist in the dusting of airbourn particulate created by the blast, inert agricultural lime is used as stemming.


1" Nipple
Veejet Nozzle(1/4")
Flat Spray
1" Cross

CHRISTMAS TREE

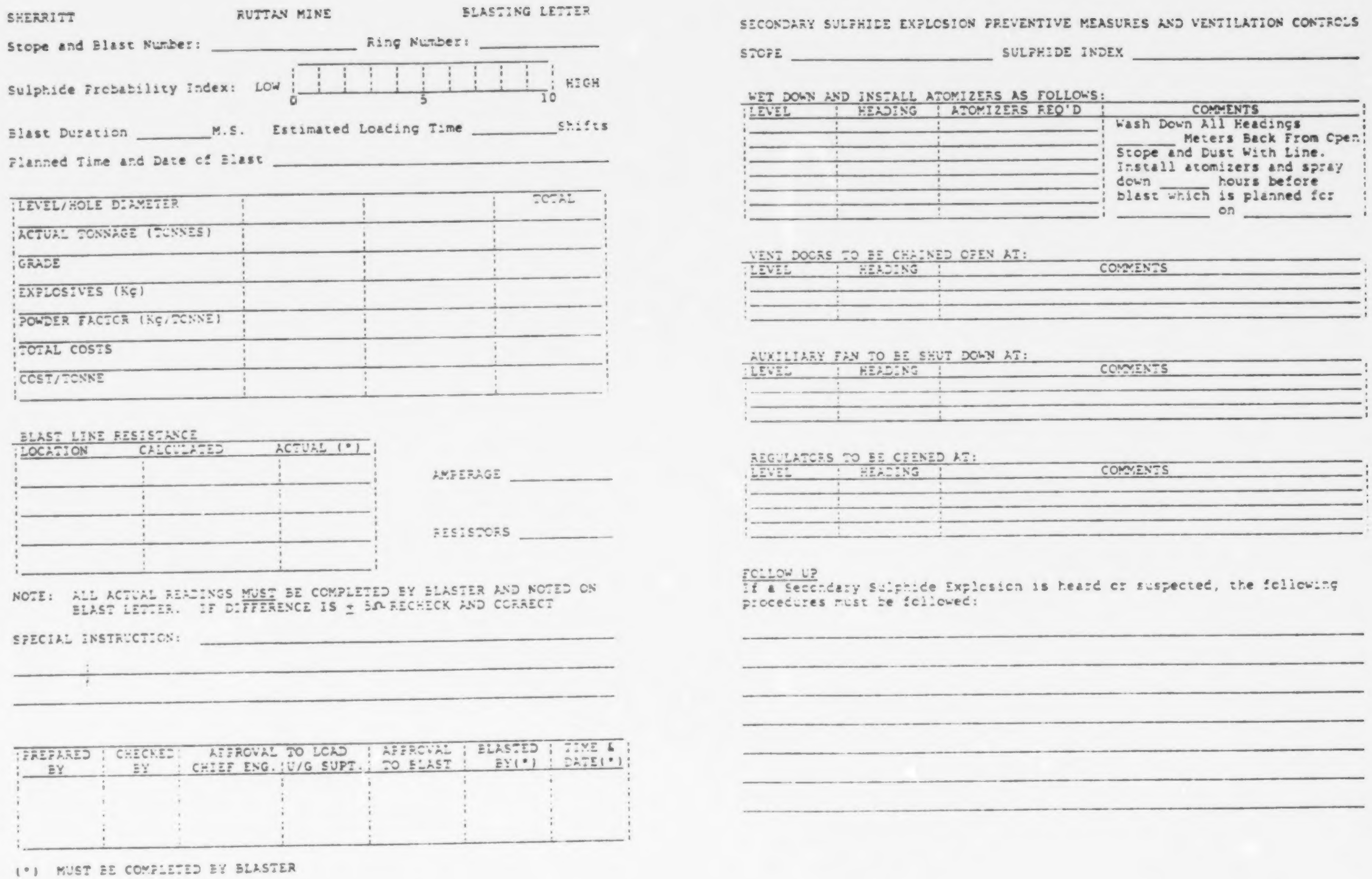
FIGURE 7

During the planning of a primary production blast, care is taken not to exceed a maximum time delay of 200 milliseconds, however, this is not always possible. Another precaution relating to blasting is the strict control of blasting times. All production blasts are restricted to shift change times when the mine is cleared of all personnel. These precautions are primarily concerned with blasting control.

In addition to these blasting controls, precautions are also taken to prevent explosive aerosol concentrations. These include rock dusting and wetting down.

Atomized water is introduced into the stope area at the top and the bottom by means of an atomizing nozzle using compressed air and water to fog the stope. The Christmas Tree, as seen in Figure 7, is a series of veejet brass nozzles with a flat spray pattern connected in such a manner as to achieve maximum spray coverage. The concept is derived from commercially available internal tank washing sprays. Prior to all blasting the stopes attendant drifts are washed and dusted with limestone for a minimum of 30 metres back from the blasting area. To achieve maximum dusting coverage a ten pound bag of lime wrapped in plastic is also suspended in the open stope and is detonated simultaneously with the blast. Diagram 1 is a actively flow chart showing a typical blasting procedure at Ruttan.

The third and final group of precautions deals with measures taken to ensure correct and consistant implementation of the required on site precautions. Within this group of measures an attempt is also made to quantify the stopes dust explosion potential. Figure 8



SHERRITT RUTTAN MINE BLASTING LETTER

Stope and Blast Number: ________________ Ring Number: ____________

Sulphide Probability Index: LOW 0 ¦ ¦ ¦ ¦ ¦ 5 ¦ ¦ ¦ ¦ ¦ 10 HIGH

Blast Duration ________M.S. Estimated Loading Time ________Shifts

Planned Time and Date of Blast ______________________________

LEVEL/HOLE DIAMETER			TOTAL
ACTUAL TONNAGE (TONNES)			
GRADE			
EXPLOSIVES (Kg)			
POWDER FACTOR (Kg/TONNE)			
TOTAL COSTS			
COST/TONNE			

BLAST LINE RESISTANCE

LOCATION	CALCULATED	ACTUAL (*)

AMPERAGE ____________

RESISTORS ____________

NOTE: ALL ACTUAL READINGS MUST BE COMPLETED BY BLASTER AND NOTED ON BLAST LETTER. IF DIFFERENCE IS ± 5Ω RECHECK AND CORRECT

SPECIAL INSTRUCTION: ______________________________

PREPARED BY	CHECKED BY	APPROVAL TO LOAD		APPROVAL TO BLAST	BLASTED BY(*)	TIME & DATE(*)
		CHIEF ENG.	U/G SUPT.			

(*) MUST BE COMPLETED BY BLASTER

SECONDARY SULPHIDE EXPLOSION PREVENTIVE MEASURES AND VENTILATION CONTROLS

STOPE ____________________ SULPHIDE INDEX ____________________

WET DOWN AND INSTALL ATOMIZERS AS FOLLOWS:

LEVEL	HEADING	ATOMIZERS REQ'D	COMMENTS
			Wash Down All Headings
			_______ Meters Back From Open
			Stope and Dust With Line.
			Install atomizers and spray
			down ______ hours before
			blast which is planned for
			__________ on __________

VENT DOORS TO BE CHAINED OPEN AT:

LEVEL	HEADING	COMMENTS

AUXILIARY FAN TO BE SHUT DOWN AT:

LEVEL	HEADING	COMMENTS

REGULATORS TO BE OPENED AT:

LEVEL	HEADING	COMMENTS

FOLLOW UP

If a Secondary Sulphide Explosion is heard or suspected, the following procedures must be followed:

____

FIGURE 8: BLAST LETTER FORMAT

shows the first and second pages of a stope blast instructional letter which is used by blasters to load and blast each individual stope.

Page one of the blast letter incorporates the blast indentification information and general blast data. This sheet also includes a sulphide probability index ranging from a low of 1 to a high of 10. The purpose of the index is not only to communicate the probability of a secondary sulphide dust explosion in the blasting area, but also to indicate its severity potential. This is best explained by the following example:

> Stope 'A' may be a stope that historically has experienced frequent sulphide blasts but can be safely cleared of sulphur dioxide without causing prolonged production delays. Stope 'B' on the other hand has not yet experienced a sulphide blast but because of its geology and proximity to critical ventilation controls has the potential to cause a major production delay and personal injury.
>
> In both cases the potential exists for a dust explosion, however, the damage potential for stope 'B' is considered higher, therefore will possibly receive a higher index rating than stope 'A'.

As can be deduced from the example, the sulphide probability index is very subjective at this stage and should be considered as a starting point for more objective classifications as Ruttans potential sulphide blast indicators become better identified.

The next section of the blast letter (page 2) is concerned with on site controls such as atomizers and Christmas Trees, and the protection of equipment required to rehabilitate the ventilation system after a blast.

One of the techniques used to speed re-entry periods after blasts with a high sulphide probability index is to short circuit the ventilation system prior to blasting, thus concentrating greater air flows over the stope to be blasted.

THE LAST 26J PRODUCTION BLAST

800-26J stope, as previously described, has had a major sulphide blast. Since then the stope has been reblasted. In this case the use of the sulphide probability index was well established, the blast site was checked prior to blasting to ensure that all the required precautions had been implemented. Mine personnel were kept over at the end of the shift when the blast was to occur and mine rescue teams were readied to rehabilitate the ventilation system if required.

The blast was initiated on time and a two man team was dispatched to check the mine for sulphur dioxide and equipment damage.

There was no evidence of a secondary dust explosion, no sulphur dioxide and no equipment damage. The 800-26J stope blast had detonated without causing a secondary dust explosion. A similar sequence of events has since occurred in other stoping areas.

CONCLUSION

Although the precautions developed at Ruttan were not all based on scientific research, they have reduced the frequency of prolonged production delays caused by the effects of secondary sulphide dust explosions. The long list of precautions that are now policy at the mine may seem like "overkill" to some operators, but if thats what is required to reduce the devastation of secondary sulphide blasts in our stopes, it will be maintained.

Drift blasting at Ruttan, although many of the same precautions are taken, has not yet experienced a reduction in secondary explosion frequency or severity. It is not unusual for a sulphide blast, initiated by drift round to repeatedly cause localized production delays and pose a threat to health and safety.

Regarding sulphide dust explosions, the major concerns facing the industry are the ability to accurately predict secondary sulphide explosions, and once predicted to economically prevent their occurance, this would obviate the need for expensive rehabilitation and create a safer working environment.

Research into explosive sulphide dust is essential to bring the Canadian Mining Industry closer to the solution of this costly problem.

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BRUNSWICK MINING AND SMELTING
BATHURST, NEW BRUNSWICK

MR. F.W. HERMANN - SENIOR PROJECT ENGINEER

THE OCCURRENCE AND CONTROL OF SULPHIDE DUST EXPLOSIONS AT BRUNSWICK MINING & SMELTING CORP. LTD. # 12 MINE

General

Over the past several years sulphide dust explosions have not been a major problem at Brunswick Mining & Smelting. However secondary dust explosions which occurred in the past resulted in the adoption of a mine policy that no blasting could be carried out with personnel underground. This does of course put a limitation on operating efficiencies particularly in development operations.

In general the occurrence of secondary dust explosions has been limited to development headings, although there has been one major occurrence in a longhole stope. Investigation following the occurrence of sulphide dust explosions has led to the identification of several common factors which were present for each event.

LUTTE CONTRE LES COUPS DE POUSSIÈRES SULFURÉES DANS LA MINE Nº 12 DE LA BRUNSWICK MINING & SMELTING CORP. LTD.

Résumé

Au cours des dernières années, les coups de poussières sulfurées n'ont pas posé de problème important pour la Brunswick Mining & Smelting. Toutefois, les coups de poussières secondaires qui se sont produits par le passé, ont entraîné l'adoption d'une politique interdisant tout tir en présence de personnel sous terre. Bien entendu, cette politique limite l'efficacité de l'exploitation, particulièrement pendant la mise en valeur.

D'une manière générale, les coups de poussières secondaires se sont produits dans des avancements de mise en valeur, bien qu'il y ait eu un coup de poussières important dans un chantier de long trou. L'étude qui a suivi ces coups de poussières sulfurées a permis de déterminer plusieurs facteurs communs.

Development Headings

The majority of sulphide dust explosions in the past three years have occurred within development headings on the 1000 level. More specifically the events occurred most frequently during the initial development of the level. Damage in the majority of cases was limited to burnt ventilation ducting and damaged fans.

Problems were most frequently encountered when one or more of the following factors was present.

1. Multiple ore headings, within close proximity, being blasted simultaneously.
2. Blasts in headings which contained a relatively greater percentage of pyrrhotite.
3. The accumulation of dust on the drift walls and back.

While secondary explosions have occurred in development headings in other areas of the mine they are not frequent and again most often occur in headings containing pyrrhotite. The other pertinent factor was the length of time between occurrences. It very seldom occurred that an area which experienced a secondary dust explosion, would experience a similar incident on the following blast.

The control of secondary dust explosions on the 1000 level was obtained by the following:

1. The drift walls and back were washed for 100 feet back from the face prior to blasting.
2. Water filled stemming cartridges were placed in the collar of each hole.
3. 3 - 4 bags of lime were placed approximately 20 feet from the face and were detonated prior to the main blast.
4. A water spray was left running behind the lime.

When correct procedures were followed secondary dust explosions did not occur. Once the level was more fully developed and development headings spread out the frequency of secondary dust explosions decreased rapidly. At the present time such explosions are rare and the precautionary measures mentioned above are no longer required except in areas of high pyrrhotite or on the rare occasions when blasts in multiple ore headings of close proximity occur.

Based on this experience it appears as though the major contributing factor to secondary explosions in development headings was the close proximity of the headings.

Stopes

Over the past several years the majority of production tonnage at Brunswick Mining has come from cut and fill stopes. The occurrences of secondary dust explosions in the stoping areas has been very rare and has generally been confined to large blasts within confined areas. That is stopes which are long and narrow and require significant delay times between initiation of the first and last row to be fired. This situation permits dust generated from the firing of the initial rows to be present in large quantities when the final row is fired. The potential problem is controlled, where possible, by breaking such blasts into two or three smaller blasts.

The lack of secondary explosions within the cut and fill stopes is most probably due to the mining cycle itself. Following the detonation of a blast there are four segments of the mining cycle which must be completed before blasting is carried out again. Three of these (bolting, mucking, and uppers drilling) make extensive use of water. Therefore, there is little or no accumulation of dust on the walls or back prior to blasting. This will not be the case with the longhole stopes and extra care will have to be taken to ensure an area is thoroughly washed prior to blasting.

The one major occurrence of a secondary dust explosion in a stoping area over the past three years occurred in a longhole stope. The No. 6 stope, located in the upper operating zone, had been idle for a period of approximately five years. When the decision was made to complete the mining of this block a new slot raise was cut and blasting commenced. Over the time frame for which the stope was idle, and during blasting of the slot raise a significant accumulation of dust occurred on the stope walls and back as well as in the stope accesses. Prior to the initial blast no attempt was made to wash down this accumulation. The secondary dust explosion which occurred was to say the least spectacular. Following the initial experience appropriate precautions were taken for subsequent blasts. These included:

1. Prewashing of the walls and back prior to each blast.
2. The placement of 10 - 12 bags of lime at all stope accesses.
4. The placement of 10 - 12 bags of lime within the stope.
5. The use of water sprays at all stope accesses and lime positions.

These measures controlled the occurrence of secondary explosions and although there was one additional incident it was due to proper procedures not being followed. The remainder of the stope was blasted without incident.

Brunswick Mining is moving away from the cut and fill mining method within 4 years a minimum of 50% will come from Open Stoping and Avoca type mining methods. This change is due, for the most part, to tonnage requirements and/or ground conditions. We feel confident that with proper control measures and operating procedures the incidents of secondary blasting may be kept to a minimum.

Summary

In summary, secondary dust explosions at Brunswick Mining are most likely to occur when one or more of the following conditions exist.

1. Multiple ore headings, within close proximity, being blasted simultaneously.
2. Blasts in headings which contained a relatively greater percentage of pyrrhotite.
3. The accumulation of dust on the drift/stope walls and back.

Control of sulphide dust explosions at Brunswick Mining has been achieved by:

1. The use of water filled stemming cartridges.
2. The use of lime and water sprays.
3. The thorough prewashing of the walls and back in the blast area.

DUPONT CANADA INC.

MR. K. CASEY - NATIONAL MARKETING MANAGER

"EXHAUST TEMPERATURE" OF EXPLOSION GASES AS A CRITERION FOR PREDICTING FIRE HAZARDS DUE TO DIFFERENT BLASTING EXPLOSIVES

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For presentation at the Annual Meeting of the CIMM, Montreal, May 1986

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ABSTRACT

When an explosive is detonated in a confined area where the air is contaminated with fine dust, the high temperature of the explosive gases may start a dust explosion. The probability of a dust explosion can sometime be reduced by switching to weaker explosives; however, this often results in an unacceptable deterioration in the quality of the blast results, such as fragmentation and rock movement. Hence, in order to minimize the probability of a dust explosion, while maintaining the quality of the blast results, it is desirable to have a reliable criterion with which to estimate the potential for such an explosion. If explosives are used unconfined, for example as in some secondary blasting, then a fair criterion is the highest temperature achieved by the explosion gases, namely their so called "explosion state temperature" T_x. On the other hand, if the explosives are used confined, such as in a stemmed borehole, then T_x is an unduely restrictive criterion; for, in this case, gases at full temperature T_x never actually come into contact with the air/dust mixture. Hence the paper proposes that under these conditions a more discriminating criterion is the explosive's "exhaust temperature" T_e, which will be defined as the reduced temperature associated with the explosion gases by the time they exhaust from the borehole; exhaust may take place either through the stemming, or through the broken rock. T_e is lower than T_x because work has been done on the rock by the expanding explosion gases between the time of detonation and the time of exhaust.

The paper will explain the concept of "exhaust temperature" and how T_e may be calculated for a specific blasting situation by means of dynamic blast simulations on the model BLASPA. The value of T_e depends on the parameters of the blast, such as explosive and rock types, charge geometry, collar and stemming, etc. Examples of simulations done for the Sherritt Gordon's Ruttan Mine will be used to show how the blast parameters can be altered so as to lower T_e, while maintaining the quality of the blast results as much as possible. Thus dust explosion hazards may be reduced without unacceptable loss in quality of the broken rock.

RÉSUMÉ

Lorsqu'on fait détoner un explosif dans un milieu confiné où l'air est chargé de fines poussières, la température élevée des gaz d'explosion peut faire déclencher un coup de poussières. On peut parfois réduire la probabilité d'un coup de poussières en utilisant des explosifs moins puissants; toutefois, ce changement donne souvent une détérioration inacceptable de la qualité des résultats du tir, comme la fragmentation et le mouvement de la roche. En conséquence, pour réduire au minimum la probabilité d'un coup de poussières, tout en gardant la qualité des résultats du tir, il est souhaitable d'avoir un critère fiable permettant d'évaluer la possibilité d'une telle explosion. Si on utilise des explosifs dans un milieu non confiné, par exemple comme dans certains tirs secondaires, un bon critère serait alors la température la plus élevée atteinte par les gaz d'explosion, à savoir leur "température d'explosion", T_x. Par contre, si on utilise les explosifs dans un milieu confiné, comme dans un trou de mine bourré, T_x est alors un critère trop restrictif; dans ce cas, les gaz à la température T_x ne viennent jamais réellement en contact avec le mélange air/poussières. En conséquence, la présente communication propose que dans ces conditions le critère soit la "température d'échappement", T_e, qu'on définira comme la température réduite associée aux gaz d'explosion au moment où ces derniers s'échappent du trou de mine; l'échappement peut se faire soit à travers le bourrage soit à travers la roche fracturée. La température T_e est plus faible que T_x parce que du travail a été fait sur la roche par la dilatation des gaz d'explosion entre le moment de la détonation et celui de l'échappement.

On explique dans la présente communication le concept de la "température d'échappement", T_e, et comment on peut la calculer pour un tir donné au moyen de simulations dynamiques avec le modèle BLASPA. La valeur de T_e est fonction des paramètres du tir, comme l'explosif et les types de roche, la géométrie de la charge, le manchon, le bourrage, etc. On utilisera des exemples de simulation effectués pour la mine Ruttan de Sherritt Gordon afin de montrer comment on peut modifier les paramètres de tir pour diminuer T_e, tout en gardant autant que possible la qualité des résultats du tir. Ainsi, on peut réduire les risques des coups de poussières sans une perte inacceptable de la qualité de la roche fracturée.

INTRODUCTION

In the underground mining of certain types of ore, the primary blasting creates clouds of fine dust which may be ignited to cause a secondary dust explosion. For example, such problems have been encountered at Sherritt-Gordon's Fox and Ruttan Mines, where the secondary sulphide dust explosions not only caused damage to some equipment underground (see reference 1) but also they generated sulphur dioxide gas; as this gas is very heavy, suffocating and toxic, production was delayed by the time it took to ventilate it. Hence the prevention of such sulphide dust explosions is of importance both to remove hazards to life and property, as well as to prevent a slow-down in production.

Several factors participate in the ignition of secondary dust explosions underground, and various steps may be taken to prevent them (see reference 1). However, it is recognized that the primary explosion of the explosives in the blast hole is one of the main factors. The paper uses blast simulations on the model BLASPA (references 2, 3) to illucidate the role played by the primary explosion of the explosives in the possible occurence of a secondary dust explosion.

I IGNITION OF DUST EXPLOSIONS BY EXPLOSIVES:

(a) Detonation and Explosion Temperatures of Explosives:

The initiation of a secondary dust explosion by the primary explosion in the borehole has usually been attributed to either the detonation temperature T_d, or the explosion temperature T_x, of the explosive. In order better to understand the hazard of dust explosions, T_d and T_x

should be reviewed (see for example reference 4). Detonation temperature T_d is the highest temperature that occurs during an explosion; it can be as high as 5,000°K.' However, it occurs only inside the explosive (see fig. 1) and lasts only for a duration of the order of 0.000005 second; hence it is very unlikely to come into contact with the dust, and so be the cause of initiation of the secondary dust explosion. Therefore it does not appear to be a good criterion by which to judge the relative hazard to be expected for different explosives. The explosion temperature T_x, on the other hand, is lower than T_d (of the order of 2,000 to 3,500°K), but it exists for a much longer duration, perhaps up to 15 milliseconds; hence it has often been suggested as a fairer criterion for judging the relative hazard to be expected for different explosives. However, the choice of T_x alone as a safety criterion usually leads to the following practical drawback. Explosives of low T_x often have less blasting performance than do explosives of high T_x. Hence the use of T_x as a criterion tends to restrict blasting to the use of low performance explosives; this can result in an unacceptable deterioration in the quality of the blast results, such as fragmentation and rock movement. It therefore appears desirable to have a more practical criterion with which to estimate the potential for a given explosive to initiate a secondary dust explosion; such a criterion is proposed in the next two sections.

(b) Principal Blasting Mechanisms:

A closer examination of what occurs during a blast can help to define a more practical criterion than T_x to predict the hazard of a secondary dust explosion. Figs. 2 and 3 explain the main mechanisms that occur during a blast underground; fig. 2 pertains to a crater blast during a slot raising operation, while fig. 3 pertains to a slashing blast once the slot is open. In either case, the first mechanism involves the generation of strong compressive stress waves that travel away from the explosion, and are later reflected as tension waves from the free faces. Rock being weaker in tension than in compression, it is the latter which initiate primary fragmentation cracks within a zone whose extent is determined by the rock strength T_o. When primary cracks have been created all the way from the faces to the explosive, secondary fragmentation then takes place through gas penetration and the presence of a semi-static stress field, a fragmentation front advancing towards the free faces at velocity C_k. When this front reaches the faces, the fully broken rock bursts out with velocity U. During all these mechanisms, the stemming material is being pushed out; gas penetration into the stemming is also taking place.

(c) Exhaust Temperature T_e:

Thus, at some stage in the blast, explosion gases reach a free face and begin to exhaust; in a crater blast, this can only occur at the one face, but in a slashing blast, it may occur at either one of the two free faces (see figs. 2 and 3). In a particular blast, the fragmentation mechanisms, as well as the time and place where gas exhaust begins, all depend on the parameters involved: rock type, explosive type, charge distribution, explosive to rock coupling, geometry such as collar, interhole spacing and hole depth, as well as the type and weight of stemming material. From a point of view of predicting the hazard of a secondary dust explosion, the key aspect is as follows: eventually the explosion gases begin to exhaust and to come into contact with the atmosphere outside the hole; having done work to break the rock and move the stemming, the temperature of such exhausting gases is now T_e, a value of "exhaust" temperature that is lower than the initial T_x.

Hence, depending on all the blast parameters listed above, the value of the flame temperature that actually comes into contact with the dust is T_e and not T_x. The paper proposes that T_e be therefore used as a criterion for predicting the hazard of a secondary dust explosion due to a given primary blast. This approach is possible because the model BLASPA (references 2, 3) can dynamically simulate all the mechanisms shown in figs. 2 and 3, as well as T_e, for any given set of blast parameters. Thus the evaluation of the potential for a dust explosion becomes no longer a function of the explosive alone, but also of the way this explosive is used in the blast. Since the simulations also predict the expected quality of the blast results, such as fragmentation and rock movement, various blasting procedures can be simulated till a reasonable compromise is found between the quality of the blast results and the hazard of a dust explosion as predicted from the simulated value of T_e.

II EXAMPLES OF APPLICATIONS AT SHERRITT-GORDON'S RUTTAN MINE:

Fig. 4 shows the lay-out for a typical drop-raising crater blast in the zone of the Ruttan Mine where dust explosions have been known to occur. To simulate such a blast and predict the exhaust temperature T_e associated with it, the model BLASPA requires a knowledge of the elastic properties of the ore in that zone of the mine; these are shown in Table I, together with other pertinent parameters concerning the blast geometry and the explosives simulated. Simulations were carried out for the Ruttan blasts to examine the effect on T_e of several parameters, as follows.

(a) Effect of Stemming:

Table II shows the results of typical simulations done to explore the effect on T_e of varying the collar length and the weight of stemming material in it. As can be seen from Table II, increasing collar length and weight of stemming can reduce T_e very significantly, from a high of 3,100°K for an unstemmed blast hole down to 2210°K for 7 feet of collar and 141 lbs. of stemming material. In the unstemmed case, the value of temperature shown corresponds to the explosion temperature T_X, since in such a case the leading exhaust gas does little work and so may remain at a temperature nearly as high as T_x. A saturation effect is also noticeable, that is the addition of more and more stemming material produces progressively less reduction in T_e. In fact, in a slashing blast, a very long collar may result in gas exhaust to the free face of the slot (see fig. 3), so that T_e becomes dependent on the burden and not on the collar.

(b) Effect of Charge Length:

Table III shows the effect on T_e of different charge lengths, simulations being presented for three different collar lengths. As can be seen from Table III, a 30% increase in explosive load increases T_e by only 50°K for a short collar; for a long collar, the increase is somewhat larger.

(c) Effect of Explosive Type:

Table IV presents simulated values of T_e with a short lightly stemmed collar, as well as for an unstemmed hole, both as a function of explosive type. As can be seen from Table IV, the highly aluminized watergel TOVEX LD 442 produces a T_e significantly larger than that of any of the lightly aluminized or non-aluminized other explosives shown in the table. It is interesting to note, however, that the T_e of a stemmed hole containing TOVEX LD 442 is essentially the same as that from unstemmed holes containing lightly aluminized watergels, and in fact lower than that of an unstemmed ANFO hole. The last entry in Table IV indicates how the risk of a dust explosion with ANFO can be reduced if the latter be diluted with 25% salt, thereby making its T_e comparable to that of the lightly aluminized TOVEX LD watergel, or the Permissible 300 Series watergels.

I CONCLUSIONS DERIVED FROM THE SIMULATIONS:

Interesting conclusions can be derived from the simulated values of T_e, as follows.

(a) **Estimate of the Critical Temperature of Sulphide Dust:**

A specific type of dust will ignite at a temperature T_c, usually called its critical temperature. T_c depends not only on the dust material, but also on the dust particle size distribution. Hence for a dust cloud from a given source, such as that from a blast at Ruttan Mine, T_c must be determined "in situ"; this is usually difficult to achieve experimentally. Simulated values of T_e, together with information from the mine, can help to bracket the value of T_c. For example, it has been reported that TOVEX LD used with 7 ft. of collar causes no secondary dust explosions; the simulated value of T_e for this situation is 1560°K. On the other hand, dust explosions have been reported when using ANFO; assuming that this occurred with a short collar, Table IV suggests a T_e of about 1900°K. Thus T_c for the Ruttan sulphide dust appears to lie between 1560 and 1900°K, i.e. an average estimated value for T_c of 1730°K.

(b) Prediction of Safe and Unsafe Blasting Procedures at Ruttan Mine:

Using this estimated T_c of 1730°K, any blasting procedure shown in Tables II to IV can be judged as likely or unlikely to cause secondary dust explosions, on the basis that T_e be greater than or less than T_c. Thus all the procedures in Tables II and III appear unsafe, while in Table IV all unstemmed blasting procedures appear unsafe, as do the stemmed procedures with TOVEX LD 442 or ANFO; on the other hand, in Table IV simulated blasts with stemmed TOVEX LD or any of the Series 300 Permissible watergels appear safe, while stemmed ANFO/25% salt seems marginal. Such predictions can be made for any other type of explosive or blast geometry which the mine might wish to consider, simply by simulating its T_e and comparing it with the estimated T_c.

(c) Hazard of Dust Explosion from Slashing Blast Procedures:

The examples of simulations to determine T_e shown in Tables II to IV pertain to crater blasts. BLASPA can, however, also simulate slashing blasts into a slot (see reference 3), and so determine T_e for such blasts. From T_e, the hazard of a secondary dust explosion can again be predicted by comparing T_e with T_c. Once more, this can be done not only for the mine's present slashing blast procedure, but for any other set of blast parameters which might be of interest to the mine staff.

(d) Compromise Between Hazard of Dust Explosion and Quality of Blast Results:

As simulations can predict the expected quality of the blast results for crater blasts (see reference 5) or slashing blasts (see reference 3), any blasting procedure that has been simulated to determine T_e can also be evaluated for the quality of its blast results, such as fragmentation and rock movement. Thus a series of simulations can be made to seek a compromise between hazard of dust explosions and quality of blast results.

FINAL CONCLUSIONS:

The main theme of the paper has been that "exhaust temperature" T_e is a superior criterion to "explosion temperature" T_x to judge the hazard of a secondary dust explosion. The reason is that, using T_x as a criterion, explosives of superior blasting performance are at once ruled out; using T_e, on the other hand the hazard of a dust explosion depends not only on the explosive itself but on the way it is used. Hence a compromise can be found between hazard of a dust explosion and good quality of the blast results. The determination of T_e for a given blast procedure is easy, as it can be simulated on the blast model BLASPA; such simulations also predict the expected quality of the blast results.

Simulated values of T_e for blast procedures tried at the Ruttan Mine appear correctly to predict the hazard of sulphide dust explosions.

The effect on T_e of various blast parameters have been examined through simulations. Stemming and explosive type appear to be the most critical parameters.

ACKNOWLEDGEMENTS:

We wish to thank sincerely the management of Du Pont Canada and Sherritt-Gordon Ltd. for their cooperation in the research that led to this paper.

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(4) M.A. Cook, "The Science of High Explosives", Reinhold Publishing Corp., 1958

(5) R.P. Favreau, D. Labine, J. Caufield, M. Wilson, "Modified Vertical Retreat Mining Method at Inco's Stobie Mine", paper presented at the 86th Annual Meeting of the C.I.M., Ottawa, April 1984.

TABLE I: DATA USED IN THE SIMULATIONS

(a) Rock Properties

Young's Modulus = 960 Kbars
Poisson's Ratio = 0.26
Density = 4.11 gm/cc

(as supplied for the upper region of the mine)

(b) Blast Geometry

Hole diameter = 6.5"
Pattern = 10' x 10'
Collar (see fig. 4)
Charge length = 3.25 - 4.3'

(c)

Explosive	Loaded Density (gm/cc)
TOVEX LD 442*	1.22
" LD*	1.17
" 330*	0.92
" 330*	1.12
ANFO 6% Oil	0.85
ANFO /25% Salt	0.85

* Registered trade name of Du Pont Inc.

TABLE II: EFFECT OF STEMMING

COLLAR (FT.)	LBS. OF STEMMING MATERIAL	EXHAUST TEMPERATURE T_e (°K)
3	41	2480
5	91	2370
7	141	2330
9	190	2260
no stemming		3100

EXPLOSIVE: TOVEX LD 442*

CHARGE LENGTH 4.3 FT.

TABLE III: EFFECT OF CHARGE LENGTH

CHARGE LENGTH (FT.)	COLLAR (FT.)	STEMMING MATERIAL (LBS)	EXHAUST TEMPERATURE T_e (°K)
3.25	3	41	2430
4.30	3	41	2480
3.25	5	91	2330
4.30	5	91	2370
3.25	7	141	2210
4.30	7	141	2330

EXPLOSIVE: TOVEX LD 442*

*Registered trade name of Du Pont Inc.

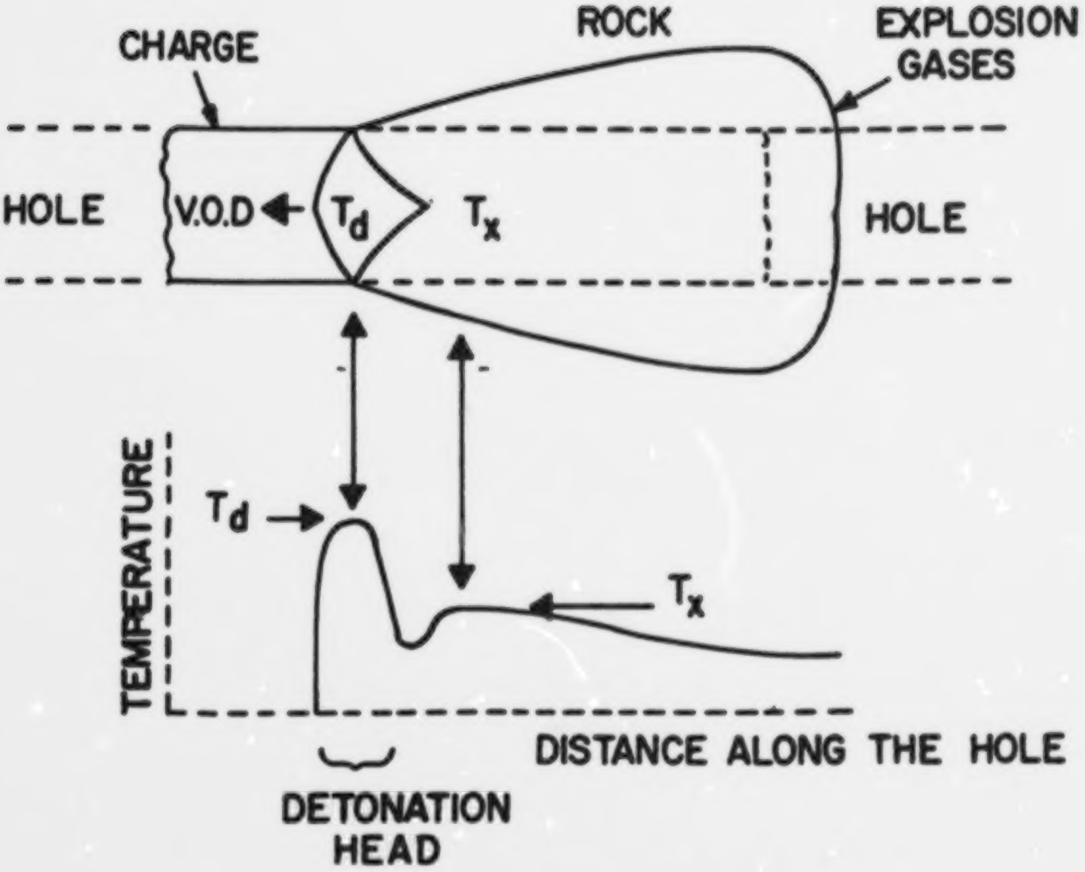
TABLE IV - EFFECT OF EXPLOSIVE TYPE

EXPLOSIVE	LOADED DENSITY (GM/CC)	STEMMING MATERIAL (LBS.)	EXHAUST TEMPERATURE T_3 (°K)
TOVEX LD 442*	1.22	41	2480
" " "	"	0	3100
TOVEX LD *	1.17	41	1630
" "	"	0	2430
TOVEX 300*	0.92	41	1600
" "	"	0	2310
TOVEX 330*	1.12	41	1660
" "	"	0	2490
ANFO / 6% oil	0.85	41	1900
" "	"	0	2780
ANFO / 25% salt	0.85	41	1720
" " "	"	0	2290

CHARGE LENGTH	4.3 FT
COLLAR	3.0 FT

*Registered trade name of Du Pont Inc.

FIG. 1: DETONATION AND EXPLOSION TEMPERATURES


CHARGE
ROCK
EXPLOSION GASES
HOLE
V.O.D
T_d
T_x
HOLE
TEMPERATURE
T_d
T_x
DISTANCE ALONG THE HOLE
DETONATION HEAD

T_d = DETONATION TEMPERATURE

T_x = EXPLOSION STATE TEMPERATURE

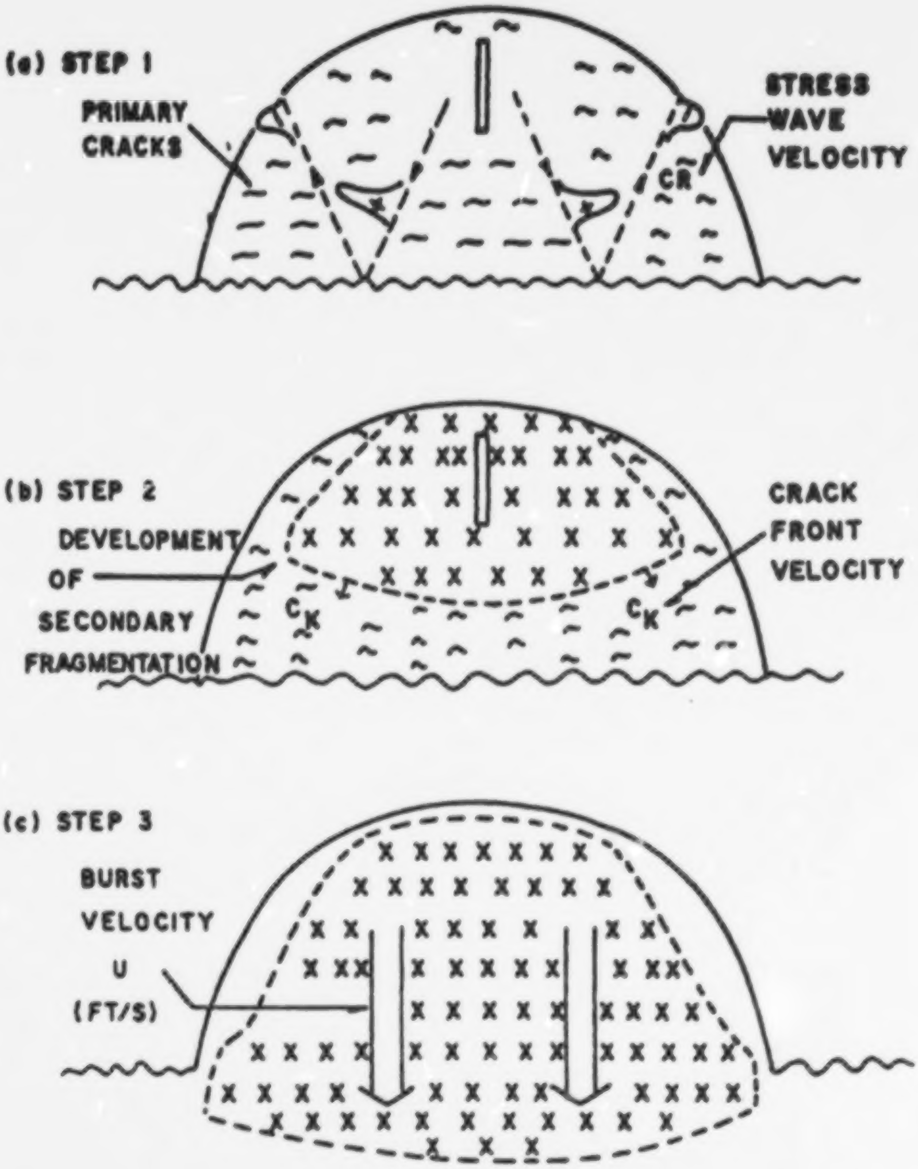
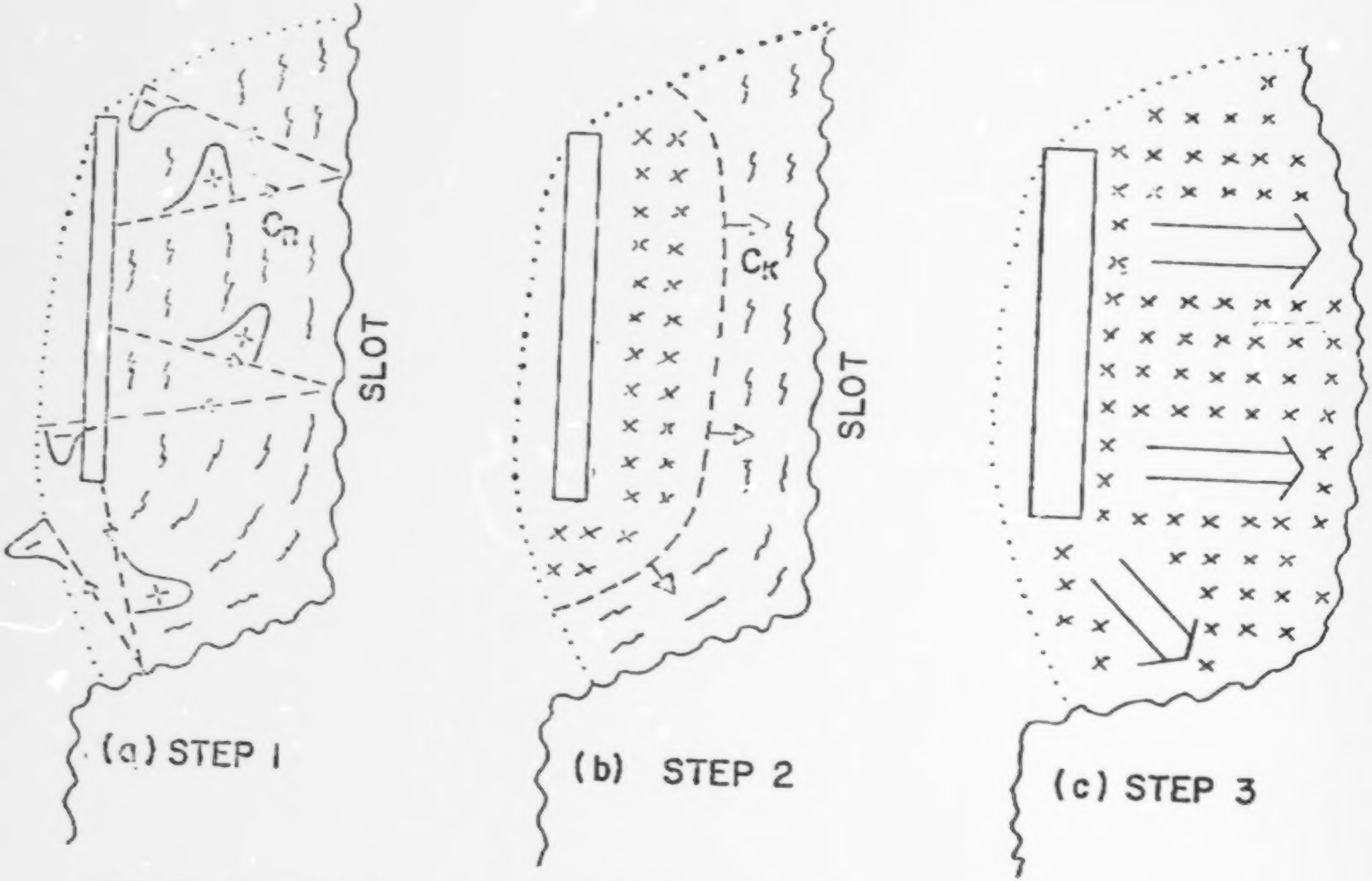

(a) STEP 1
PRIMARY CRACKS
STRESS WAVE VELOCITY
CR
(b) STEP 2
DEVELOPMENT OF SECONDARY FRAGMENTATION
CRACK FRONT VELOCITY
C_K
C_K
(c) STEP 3
BURST VELOCITY U (FT/S)

FIG. 2: MECHANISMS IN A CRATER BLAST


C_n
SLOT
C_K
SLOT
SLOT

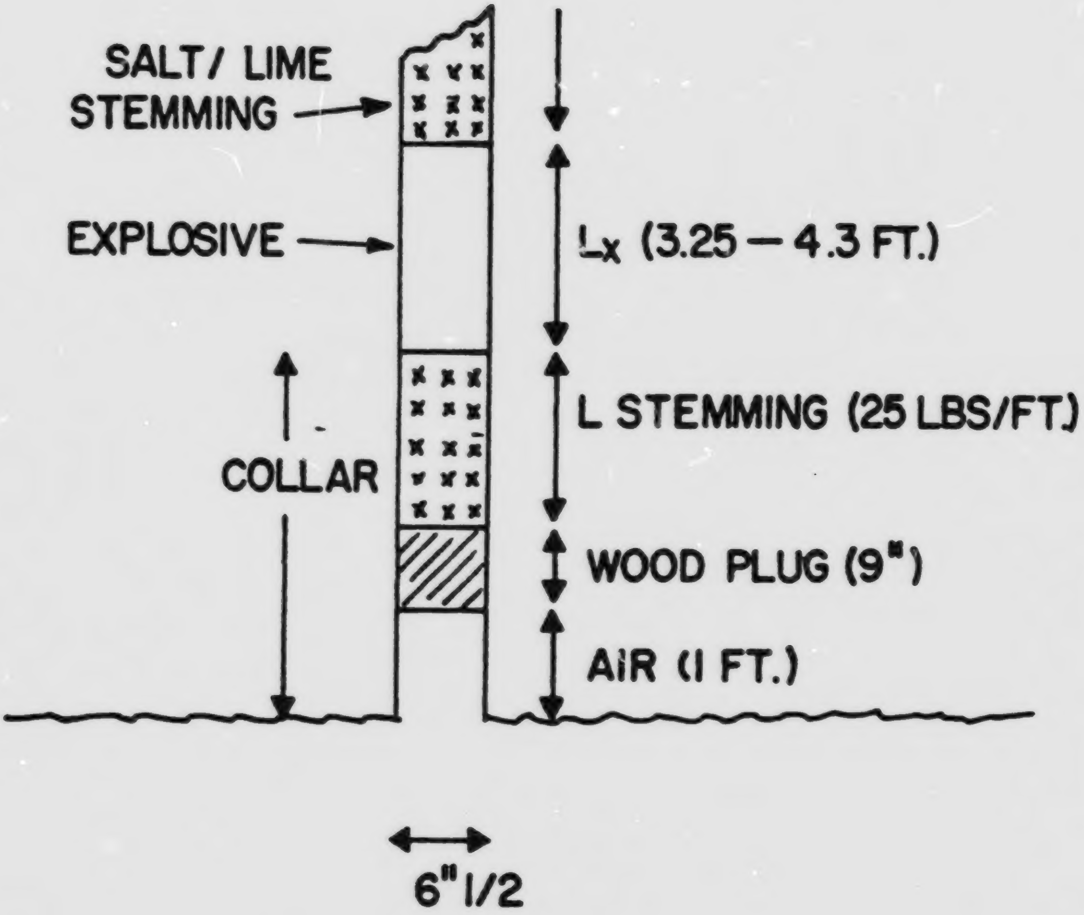
(a) STEP I

(b) STEP 2

(c) STEP 3

FIG. 3: MECHANISMS IN A SLASHING BLAST

FIG. 4: GEOMETRY FOR CRATER BLAST


SALT/ LIME STEMMING
EXPLOSIVE
COLLAR
L_x (3.25 – 4.3 FT.)
L STEMMING (25 LBS/FT.)
WOOD PLUG (9")
AIR (1 FT.)
6" 1/2

NORANDA RESEARCH CENTRE

MR. K. WHEELAND - HEAD - DEPARTMENT OF ENVIRONMENTAL
TECHNOLOGY

COUPS DE POUSSIÈRES SECONDAIRES DE MINERAIS SULFURÉS : CAUSE, PRÉVENTION ET LUTTE

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RÉSUMÉ

La Noranda, conjointement avec le CANMET et plusieurs compagnies minières et organismes gouvernementaux, mènent une étude de l'état actuel des connaissances portant sur les coups de poussières de minerais sulfurés. En plus des renseignements provenant du Groupe Noranda et de la documentation publiée, les auteurs ont eu accès à des renseignements inédits d'autres sources obtenues grâce à un questionnaire et à un suivi.

La présente communication résume les résultats de l'étude, livre les principales conclusions et suggère des domaines pour une recherche ultérieure.

THE CAUSE, PREVENTION, AND CONTROL OF SECONDARY DUST EXPLOSIONS OF SULPHIDE ORES

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ABSTRACT

A review of the state-of-the-art regarding sulphide ore dust explosions is being conducted by Noranda, in co-operation with CANMET and several mining companies and government agencies. In addition to Noranda Group information and published literature, unpublished material has been obtained from other sources via a questionnaire and follow-up.

The presentation summarizes the results of the review, discusses the major conclusions and suggests areas for further investigation.

INTRODUCTION

This paper briefly describes an evaluation conducted by Noranda Research in 1979/80, and then presents the key points of a state-of-art review which is now underway. This review is largely based on information provided by the companies and individuals participating in this conference. It should therefore serve as both an overview of our collective knowledge, and a guide in identifying areas for further action.

1 PREVIOUS EVALUATION (1979/80)

1.1 Scope of Work

In early 1979, three Noranda Group mines indicated that secondary dust explosions or fires following blasting of sulphide ores were a concern although one of them (BMS-M) had considerable experience in dealing with them. Noranda Research Centre (NR) undertook a study to evaluate the factors involved and to identify preventative techniques. After consulting with the mines and CANMET, and a review of the literature, a series of tests were conducted to examine explosivity, sulphur content and effect of diluents for 19 dust and ore samples

Explosivity tests were carried out using a Hartmann apparatus, and ignition temperatures were established by differential scanning calorimetry.Determination of sulphide and sulphate was by standard methods.

1.2 Results, Observations and Conclusions

The results of the explosibility tests are shown in Table I, the effect of diluents in Table II, and the ignition temperatures in Table III.

The major observations and conclusions were:

*Samples from high-risk areas were >29% S, and no flame occurred at <23% S.

*Minimum dust concentration was 0.5 kg/m3.

*All diluents tested were equivalent (Ca(OH)2, KCl, MgSO4, Mg CO3,low S ores).

*The apparent ignition temperature range was 250-425oC.

*The most effective suppression method reported (for development headers) was the use of water-filled ampoules by Brunswick Mining. Results were mixed for wall washing and/or concurrent blasting of bags of lime or cement.

1.3 Major Recommendations Proposed

1.3.1 Information

*Distribute NR report widely.
*Write up and distribute incident reports.
*Assess suppression techniques.

1.3.2 Risk Identification

*Do exposivity test for all >23% S ores.
*Assess identified risks as part of mine planning.

1.3.3. Prevention

*Test water stemming at all mines with risks.
*Wet down walls where practical.
*Continue lime blasting, but try to improve reliability.
*Document Noranda and others experience.

2 ADDITIONAL INFORMATION (1980/85)

In 1983, the prospect of improved control for large stope blasts was discussed with Brunswick Mining and Heath Steele personnel. The situation was that secondary explosions were a frequent occurrence, the extent was limited by use of water sprays at all entryways, and there was sufficient time to evacuate fumes prior to the next shift. All personnel were aboveground at the time of the blast.

There was no apparent risk to personnel injury, damage to equipment or production delays.It was therefore agreed that the existing technique of control rather than prevention was adequate and no further work would be done.

3 STATE-OF-ART REVIEW (1986)

3.1 Background

Informal discussions were held over several years with both the US Bureau of Mines (USBM) and CANMET regarding possible further evaluations of sulphide dust explosivity on a larger scale than possible in Noranda Research's facilities, up to full-scale experimental mine blasts. Ore and dust from Brunswick Mining were provided on two occasions to USBM, and laboratory tests were conducted to quantify the explosivity characteristics. The results, which were similar to those we obtained in 1980, are shown in Table IV.The feasibility of conducting full-scale tests in USBM's experimental mines at Pittsburgh was also established. In early 1985, CANMET indicated that it was planning to undertake an investigation of secondary dust explosions as an in-house project, as soon as laboratory modifications and organizational changes had been completed. Noranda agreed to co-operate with respect to samples, information and advice, and to consider in-mine evaluation of any promising technology emerging from the research.

3.2 Scope of Work

While awaiting the completion of the CANMET facilities, Noranda decided to proceed with a state-of-art review, with particular emphasis on unpublished information.A questionnaire and list of recipients were prepared, in consultation with CANMET, USBM, Ontario Ministry of Labour and others. In parallel, a further review of the literature was conducted (Appendix A, Bibliography).Also, to the degree possible within the limited time and funds available, discussions were held with several companies and government agencies. Finally, investigations were started at some Noranda mines to augment the available information regarding specific incidents.

3.3 Preliminary Results of Questionnaire and Interviews

Most of the comments received to date regarding control measures are summarized in Table V. Many of the respondents are at this workshop and will be presenting considerable further information and details. One recurring observation is that water is the best deterrent, whether it is used to wash down the area, as a spray or fog in or adjacent to the blast area, as a stemming material, or as a concurrently-blasted wetting agent. Another point made by many is that incidents occur" when standard practises are not followed". A final comment is that opinions vary within and between companies regarding the efficacy of various practises.

Appendix B includes further details regarding Brunswick Mining, Heath Steele, Sherritt Gordon and Elura which were received as part of the questionnaire response.

3.4 In-mine Noranda Investigations

In addition to the quite detailed investigation that GECO has conducted and reported, two other operations have commenced examinination of incidents in some detail- Mattabi and Matagami's Norita Mine (plus the Mattagami Mine as a control). For known occurrences, factors such as blast design (explosive type, powder factors, sequencing, patterns,..),physical and chemical mineralogical characteristics, and other mine design parameters such as ventilation are being examined. Laboratory explosivity testing might also be conducted. It is expected that these evaluations will assist in prediction and prevention.

To date, considerable data have been collected including detailed mineralogy for Norita, a history of occurences, locations, blast design and practise, production delays, preventative measures in use as well as mine design including ventilation flows.

Both Norita (Zone A) and Mattabi ores contain a considerable amount of sulphide mineralization (an average of 30% and 28%), but the mineralization is quite different- they are a copper and a zinc mine respectively. Both mines use bulk mining methods, but with different blasting practises. Hence the evaluations should generate considerable information on the relative importance of a number of factors.

4 RECAP OF WHAT WE KNOW (?)

4.1 Predictions

Table VI indicates in point form some of the factors related to occurrence, hence is a starting point for considering both prevention and areas of ignorance. However, at this stage, "previous experience" tends to be the most common basis for action, rather than a systematic assembly and interpretation of data.

4.2 Prevention

Table VII lists a number of practises to avoid or minimize dust explosions, most of which are practised in some combination and form by all companies with this problem. The value of these practises under various circumstances appears to be largely unquantified, although some operations report having conducted systematic studies (e.g. of water stemming by BMS-S). Some practises apparently work for some and not for others, due perhaps to different conditions or procedural details.

4.3 Control

Limitation of the degree or extent of damage is addressed in Table VIII. If there is no damage to people or property and no production delay, there is no problem!

5 POSSIBLE FURTHER ACTION

5.1 The Areas for Possible Investigation

In Tables IX-XI, some of the uncertainties regarding generation, avoidance and control are listed, with no claim to completeness or priority-setting. During this workshop the mine operators and technical people are interacting to share information, ideas, and evaluations in a manner not likely to be repeated. The results should be a comprehensive list of possible actions, (as well as a compilation of the presentations and an excellent set of personal contacts). What do we do with all this potential for increasing our wisdom?

5.2 Planning Algorithm

The sequence of steps shown in Table XII is familiar to many of you, and illustrates the fact that we need to know where we are going and why before we start out on a journey or a project. With goals and justification firmly established, we can then consider how to proceed and whether the cost is in proportion to the benefits. Finally, it is necessary to address the remaining questions of who pays, who performs , who manages, what the final product will be and when it will be delivered.

5.3 The Next Steps

A suggested approach (which can be revised based on the workshop inputs) is to do the following:

During the workshop:

*establish what we know
*list the possibilities for action
*discuss needs, goals, priorities
*agree on how to document/ exchange existing information
*define a mechanism for developing a research plan (if warranted)

After the workshop:

*Prepare/distribute proceedings (CANMET has offered to do this).
*Proceed with agreed means of documenting/distributing existing information
*Proceed, if agreed, to develop a research plan
*(Noranda should complete the state-of-art report and the in-mine assessments at Mattabi and Norita in any case).

6 FINAL COMMENTS

GECO has done a great service to us all in organizing this workshop, and Dr. Enright and all the other speakers and participants have shared their knowledge and ideas in an open and productive manner.

It will be unacceptable to all of us if this knowledge is not documented, disseminated, utilized, maintained up to date and expanded upon.

The responsibility is ours and the yardstick for measuring our success will be the presence or absence of significant occurences in our or other companies' mining operations.

TABLE I

EXPLOSIBILITY / FLAMMABILITY CHARACTERISTICS OF SULPHIDE ORE DUSTS

Sample	Sulphur,%			Minimum O2 level,%[1]		Minimum dust concentration[2]	
	Total	Sulphide	Sulphate	Flame	Explosion	Flame	Explosion
Orchan #1	23.2	23.1	0.14	N.O.	N.O.	0.5 oz/cuft	0.6 oz/cuft
#2	17.2	16.9	0.13	N.O.	N.O.		
#3	43.1	42.9	0.24	40	50		
#4	24.5	24.4	0.09	N.O.	N.O.		
#5	24.9	24.7	0.22	100	100		
#6	14.6	12.1	2.51	N.O.	N.O.		
#7	44.2	44.0	0.26	40	< 100		
#8	47.0	46.8	0.21	40	< 100		
#9	25.8	25.7	0.11	100	N.O.		
Mattabi #6	29.7	29.3	0.43	50	80	1.25 oz/cuft	2.0 oz/cuft
#8	23.3	22.8	0.87	100	N.O.		
Brunswick	33.3	32.7	0.58	50	60	1.25 oz/cuft	2.0 oz/cuft
Geco #1	29.8	28.6	1.24	N.O.	N.O.	0.6 oz/cuft	1.25 oz/cuft
#2	36.8	36.0	0.82	50	80		
#4	15.4	14.9	0.52	N.O.	N.O.		
#5	10.9	10.5	0.43	N.O.	N.O.		
#6	33.5	32.9	0.58	80	N.O.		
Mattagami	14.5	14.1	0.40	N.O.	N.O.		
Gaspe	2.6	2.5	0.15	N.O.	N.O.		

[1] Dust concentration 6.25 oz/cuft:, N.O. indicates "not observed" at 100% O_2

[2] Not determined for samples with no data indicated.

TABLE II

%S LEVEL TO WHICH THE SAMPLE MUST BE DILUTED TO PREVENT THE PROPAGATION OF A FLAME IN 100 % O_2

Sample No.	Initial % S	Diluent					
		$Ca(OH)_2$	$CaCl_2$	$MgSO_4$	$MgCO_3$	Gaspé	Geco #5
Orchan #3	43.1	30.4	28.2	30.6	34.3	26.8	26.7
Brunswick	33.3	26.4	27.3	27.3	28.2	-	-
Mattabi #6	29.7	26.6	-	-	-	-	-
Geco #2	36.8	30.0	24.4	-	-	-	-

TABLE III

IGNITION TEMPERATURE & SULPHUR CONTENT OF SELECTED SULPHIDE DUSTS

Sample	% S	T_{ign}, °C
Orchan #1	23.2	390
#3	43.1	300
#4	24.5	390
#5	24.9	375
#7	44.2	415
#9	25.8	390
Mattabi #6	29.7	425
#8	23.3	410
Brunswick	33.3	405
Geco #2	36.8	250

Table IV

DUST EXPLOSIVITY TESTS (by USBM) IN 20 - L CHAMBER

	Sulfide Ore		Pgh. Coal,	Oil Shale
	12/83 sample	7/85 sample	bituminous	23 gal/ ton
Assay Zn	11.5 %	11 %	–	–
Pb	4 %	4 %	–	–
Fe	–	23 %	–	–
S	37 %	30 %	–	–
Heating value, BTU/ lb	1850	1420	13,800	2,140
Size, -200 mesh, %	85 %	96 %	80 %	58 %
$\bar{D}s$, μm	27	16	30	22
$\bar{D}w$, μm	44	23	50	88
Lean Limit , g/m^3 with 5000 J ignitors	~ 550	~ 650	90	~ 700
Max. Pressure Rise, bar	~ 2	~ 2	5.5	~ 2
Max. Pressure Rise Rate, Kst, bar./sec	~ 2	~ 3	~ 30	~ 2.5

TABLE V

SUMMARY OF PRACTICES INDICATED BY RESPONSES TO CANMET & NORANDA QUESTIONNAIRES

	COMPANY	WASH AREA	BLAST LIME	BLAST WATER	SPRAYS	CHANGE EXPLOS.	CHANGE VENT'N	SHORTEN DELAY
1.	Cominco (W. Russell)	y		y			y	
2.	Hudbay (F. Yungwirth)	y	y		no			
3.	Kidd (P. Fleming)	y	y					
4.	Matagami (J–P Chauvin)	y	y?	–	–	y	y	y
5.	Nanisivik (S.Blaho)		y					
6.	Sherritt (P. Goodwin etc.)	y	y		fog	y		y
7.	Westmin (P. Schultz)	y	y		y			
8.	BMS–M/H–S (various)	y	y	y	y	y		
9.	Mattabi (J. Wotton)	y	y		y			
10.	Elura (DuPont) (A. Webster)	y	y		fog			y

TABLE VI

FACTORS IN PREDICTING OCCURENCES OF SECONDARY DUST EXPLOSIONS

- % S
- friability
- detonation delays
- explosive type
- dustiness of area
- misfires/undetonated explosives/primer cord
- mining method
- previous experience
- geometry of void and workings

TABLE VII

CURRENT PRACTICES USED
TO PREVENT SECONDARY DUST EXPLOSIONS

- non-aluminized/low temperature explosives
- shorter delay times (< 200 ms)
- water stemming/bags (blasting)
- washing down area
- fogging prior to blast
- inert stemming/blasting
- no blasting of adjacent areas

TABLE VIII

CURRENT PRACTICES USED TO CONTROL SECONDARY DUST EXPLOSIONS

- direction and quality of ventilation
- ventilation door control (BMS)
- clear men from mine
- equipment removed from area
- check air quality before re-entry

TABLE IX

AREAS FOR INVESTIGATION RE CAUSES

- pertinent characteristics of explosives (RV)
- pertinent characteristics of mineralogy
- pertinent characteristics of blast design
- risk of other reaction products (H_2 , H_2S)
- dust explosivity characteristics (USBM/CANMET)
- effect of scale–up
- continued documentation

TABLE X

AREAS FOR INVESTIGATION RE PREVENTION

- oxygen starving techniques/oxygen negative explosives (KM)
- explosive formulation (RV)
- blast design re control of dust and ignition
- quantify effectiveness of "known" cures
- more effective suppressants (USBM)
- triggered barriers (USBM)
- continued documentation

TABLE XI

AREAS FOR INVESTIGATION RE MINIMIZING CONSEQUENCES

- continuous SO_2 monitoring
- non-flammable ventilation tubing
- ventilation model/control
- continued documentation

TABLE XII

PLANNING ALGORITHM FOR FURTHER WORK

1. What is the **justification** (if any) for further work?
2. What are the measurable **goals** ?
3. What are the **priorities** ?
4. What are the consequent **scopes** of work?
5. What are the **costs** for each project?
6. What are the available/suitable **resources** (facilities and organizations)?
7. What is the consequent **plan**, steps, timing, costs, responsibilities, sources of funds, organization, etc.)?

APPENDIX A

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APPENDIX B

SELECTED RESPONSES TO NORANDA RESEARCH QUESTIONNAIRE ON SECONDARY DUST EXPLOSIONS OF SULPHIDE ORES:

B.1 Brunswick Mining, Bathurst, New Brunswick (G. Greer)

B.2 Heath Steele, Newcastle, New Brunswick (K. Daniel)

B.3 Sherritt Gordon, Leaf Rapids, Manitoba (C. Bellingham)

B.4 EZ Elura, Australia (L.J. Hyde)

P.O. Box 6000
Fredericton, N. B.
E3B 5H1

July 25, 1986

Noranda Research Centre
240 Hymus Boulevard
Pointe Claire, Quebec
H9R 1G5

Attention: Mr. K. G. Wheeland
Head, Environmental Technology

Dear Mr. Wheeland:

Subject: Secondary Dust Explosions in
Sulphide Ore Mining. Your letter of July 11, 1986

My experience with sulphide dust explosions and sulphide fires was during my employment with Brunswick Mining from 1964 to 1974.

Some of the procedures we used at that time to reduce the dust explosions are as follows:

1. Long-hole blasting: When the mine started in 1964 there wasn't any sulphide blasts as far as I can remember. Perhaps this may have been due to the fact that dust accumulations were low. Nevertheless I do recall sulphide blasts becoming a concern around 1967 or 1968. After the experience of walking into SO_2 accumulations for a while we began to take steps to minimize the generation of sulphur dioxide during long hole blasts, using lime and air/water sprays. The steps included:

    (a) Placing a bag of lime (carbonate) in between each row of rings in the footwall, hanging wall and intermediate drifts of the area to be blasted (on each level). As well, two large plastic bags of water were placed adjacent to the lime bags. The lime bags were detonated with a blasting cap delayed with each row of rings.

(b) Air and water sprays were also installed at the end of each final row of holes to be blasted at all accesses on all levels of the stope to be blasted.

(c) Prior to loading the holes the walls and backs of all accesses were washed down to remove dust accumulations.

(d) Where possible all wood and other combustible material were removed from the blasting site and as well anything on wheels (mine cars, muck machines) were taken from the blast area and lifted off the rails.

(e) All empty explosive containers were returned to surface.

(f) The entire mine was cleared of personnel-this involved each person turning in his tag to the supervisor once he came to surface. This still was not a fool-proof system and the Captain on duty often had to call people to see if they had tagged out (especially staff and maintenance people).

(g) All ventilation doors on each level of the stope to be blasted were braced open.

(h) After the blast was made from surface about two hours were allowed to elapse and then the mine rescue team was sent down to place the vent doors in their proper position, to check the ventilation and to examine the blast.

Long hole blasts were usually scheduled prior to the shaft inspection and maintenance shift (no production or development crews scheduled) and this was at 8:00 a.m. Saturday. This allowed eight hours of clearance before the next regular shift came on. As we caught up on the development and drilling work, long-hole blasts became larger and more routinely scheduled and problems with sulphide blasts in the long-hole stopes became less frequent. Thus I believe a combination of the steps taken helped to lessen the problem: Use of lime and water, removal of combustible materials and good positive ventilation.

2. Development Headings: (non-regulated blasting times) The steps to reduce SO_2 generation in sulphide development headings (jackleg) were:

   (a) Wash backs and walls.

   (b) Install air/water sprays.

   (c) Hand 2 or 3 lime bags at site.

   (d) Turn fan to vent duct on after the blast.

   (e) Workers went to refuge station after blast detonation.

3. Slot raises (drop raises) - Long - hole slopes

   Even though these were conducted throughout a shift, prior to the development of scheduled blast times-lunch and quitting time, I do not recall any problems with sulphide explosions.

4. Slusher and Drawpoint secondary blasting

   In the early years of the operation and prior to the change to the mechanized cut and fill mining method these were the greatest generators of sulphur dioxide. In most cases the ventilation system was not as highly developed as it could be and a lot of problems resulted from recirculation. In secondary blasting block holing was rarely used and sand blasting was the common feature. Attempts made to reduce sulphide explosions included placing small bags of lime next to the charge as well as a small plastic bag of water. Air and water sprays were also installed in the drawpoints and box holes but these were difficult to maintain. As well the washing of the backs and walls of the drawpoints was not always carried out. The hazards from sulphide blasts at secondary blasting sites was ultimately reduced by limiting such blasts to lunchtime and quitting time. Workers were also provided with "sulphur masks" which were frequently used.

5. Mechanized cut and fill method

The conversion of open stope blasting to cut and fill on the lower levels of Brunswick (1400 W and 1900 down) starting in 1971 did not produce the same sulphide dust problems as the long-hole stopes particularly the secondary blasting. The latter was eliminated in the new method because of the smaller muck. Nevertheless the development headings (jumbos) still required treatment with both lime and water which were placed in the holes along with the explosives. The art of which this has progressed should be discussed with Mr. Herman Derbuch, Mine Superintendent, Brunswick Mining. As mentioned before blasting schedules have changed from one of "at anytime" to a fixed schedule of lunch and quitting time when workers have left the active working faces. I believe all primary blasts are now scheduled for surface detonation when the mine is clear of workers.

In 1977 a record of all unusual occurrences was required by the N.B. Mining Regulation 77-58. Sulphur dioxide occurrences (from sulphide blasting) has been maintained by the Occupational Health and Safety Commission since that time. In some cases there are detailed reports which were compiled by Brunswick Mining and Heath Steele. The unusual occurrence reports pertaining to sulphide dust explosions can be obtained from Ken Daniel, Chief Inspector, Occupational Health and Safety Commission, P.O. Box 6000, Fredericton, N.B. E3B 5H1. As well Stu Cowen, with the OHSC, was involved in some of the sulphide explosions because of his job as mine rescue superintendent (phone 506-658-2460) in Bathurst, between 1970 (?) to 1984.

I have enclosed a couple of papers published in the June 1977 issue of the CIM Bulletin concerning underground sulphide "Hot Muck" Mine Fires for your reference. Although the bulk of the material is dealing with a stope sulphide fire there is some mention to sulphide dust explosions (see page 5 78, 89) A student, Chris Dupont, who worked at Brunswick Mining, prepared his thesis on the Brunswick Sulphide Fill Fires while at the Technical University of Nova Scotia. I do not have a copy of it but Brunswick or TUNS may be able to get you a copy. It may cover some aspects of secondary dust explosions.

The best source of information, I believe, would be Robert Baker, and the ventilation department of Brunswick Mining.

If you need any additional information please contact me.

Yours truly,

George Greer

GEORGE J. GREER, P. Eng.
Director
Mineral Development

GJG/clg

Enclosure

c.c. Bill Denny
Ken Daniels

cc. Bill Denn
Ken Dance

Centre de Recherche Noranda
240 boulevard Hymus
Pointe-Claire, Québec H9R 1G5
Tél. (514) 697-6640
Telex 05-822647

noranda

11 July 1986

G. Greer
New Brunswick Dept. of
Natural Resources
P.O. Box 6000
Fredericton, N.B.
E3B 5H1

SECONDARY DUST EXPLOSIONS IN SULPHIDE ORE MINING

Your help is requested in identifying sources of information (particularly unpublished and even unwritten!) on the above topic. This information will be used to compile and distribute a report on existing know-how, which should help to minimize the risk of damage from such explosions and provide a basis for further technology development.

THE PROBLEMS (Technical and Information)

During the blasting of high sulphide ores, dust clouds may be created and ignited, resulting in a secondary explosion, and release of considerable volumes of sulphur dioxide. The consequent pressure, heat and toxic gases can result in damage to personnel and property, as well as production delays.

Note: The only indications of an incident may be reddish dust or the smell of sulphur dioxide.

Prediction and prevention of such occurrences is an inexact science, information on incidents has generally not been documented, and existing know-how is not widely distributed and used within the mining industry.

THE PROPOSED APPROACH

Noranda is preparing a compilation of current knowledge and guidelines on this topic, with the co-operation and moral support of CANMET, as well as several mining associates and inspectorates. This report will document case histories, and provide guidelines for anticipating, minimizing and controlling the effects of such explosions. This will provide both immediately useful information, and a basis for considering further technology development.

YOUR ASSISTANCE

Please take a minute to complete the brief questionnaire attached, and return it to me.

Thank you for your co-operation,

K.G. Wheeland
Department of Environmental Technology

QUESTIONNAIRE

SECONDARY DUST EXPLOSIONS IN SULPHIDE ORE MINING

1. Have you or your company any experience or knowledge on the above topic?

__✓__ Yes ________ No

2. If "YES", whom may I contact for further information?

__✓__ Yourself or R.W. Baker - Brunswick Mining
S. Cowen - OHSC.

3. Please attach or enclose any readily-available information such as:

- REFERENCES
- OTHER SOURCES
- COMMENTS

More specific information can be obtained from the Occupational Health and Safety Commission. P.O. Box 6000 Fredericton N.B. E3B5H1. They have kept a record of all unusual occurrences such as sulphide dust explosions - contact person is Ken Daniel - Chief Inspector (formerly chief engineer at Heath Steele and Stuart Cowen - Mine Rescue Supt. now located at 400 Main Street, Chesley Place Saint John, N.B. E2K 4N5

Ken Daniel - # 453-2467
Stu. Cowen # 658-2460
Robert Baker - # 546-6671

Please return this page to the undersigned at your earliest convenience and thank you for help.

Name and title of respondent:
GEORGE GREER
DIRECTOR
Mineral Development Branch - N.B.
Telephone: 453-2206 (506)

Return to:
Mr. K.G. Wheeland
Head, Environmental Technology
NORANDA RESEARCH CENTRE
240 Hymus Boulevard
Pointe Claire, Quebec, Canada
H9R 1G5

OCCUPATIONAL HEALTH AND SAFETY
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ET DE LA SECURITE AU TRAVAIL
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NEW BRUNSWICK
NOUVEAU BRUNSWICK

August 8, 1986

Mr. K.G. Wheeland
Head, Environmental Technology
Noranda Research Centre
240 Hymus Boulevard
Point Claire, Quebec
H9R 1G5

Dear Mr. Wheeland:

Re: Secondary Dust Explosions in Sulphide Ore Mining

First, I must say, it was a pleasure to meet you during your recent visit to Fredericton.

As requested I am enclosing a completed copy of your questionnaire for record purposes.

In our current files, there are no significant and comprehensive references to secondary dust explosions. Where there has been an ancilliary effect such as a fire in ventilation ducting or timber the occurrence has been reported as required for "Unusual or Dangerous Occurrences". However all dust explosions are not reported to us. I have attempted to go back to old files covering the '70s and into 1982 but have not been successful in finding any comprehensive records of sulphide dust explosions. Again, occasional reference may be made in "Dangerous and Unusual Occurrence" files where there has been other associated effects. However, where they are reported, they are not sufficiently specific as to the actual site of the secondary explosion, to be useful in an analysis.

The only further comments I may relate, derive from my experience at Heath Steele Mines from 1967 to 1985.

1. Heath Steele Mines did experience relatively frequent occurrences of sulphide dust explosions. Generally no personal injuries occurred although there were some cases where personnel did suffer from some SO_2 inhalation.

2. Amelioriative measures taken included:

   (a) washing walls where practicable prior to blasting;
   (b) use of compressed air/water sprays in all access headings to the blast site;
   (c) use of hydrated lime in bags suspended in drifts or stacked with an explosive charge to detonate with the stope blast, or suspended below a 'crater' blast;
   (d) use of water stemming in development headings;
   (e) ban on the use of drill cuttings for stemming blast holes.

3. No analysis was done to determine whether sulphide dust explosions could be related to mineralogy, sulphur content, blasting pattern and timing, proximity and relative timing of adjacent blasts, or other possible fundamental reason.

4. When sulphide dust explosions occurred, investigations were directed more to possible omission of preventative measures than to seek basic causes.

5. Personnel protection was obtained by carrying out blasting operations only when all personnel were removed from underground, and verification, prior to allowing men to re-enter the mine, that the mine atmosphere in the shaft and stations was satisfactory. Also all personnel were required to carry "sulphur bags" which gave limited protection if caught in SO_2 gas.

Should any further pertinent information come to hand I will ensure it is forwarded to you. We will be most interested in your findings and request that we get copies of any reports that you may publish on the matter.

Yours truly,

K. E. Daniel
Manager, Mine Safety

KED/jlr

cc R. Brian Connell
W.C. McQuoid

SHERRITT GORDON MINES LIMITED

cc: PHG

PLANNING MEETING
JANUARY 15, 1981
SULPHIDE BLAST PREVENTION

Present: C. Bellingham -Chief Mine Engineer
D.B. Olszowiec -Mine Planning Supervisor
B. Kellett -Projects Supervisor
G. House -Chief Safety Engineering
B. Thompson -Dupont of Canada
E. Kardas -Senior Planning Engineer
A. Morris -Senior Planning Engineer
D. MacKinnon -Mine Captain; Operations
E. Kozy -Blasting Foreman

The recent sulphide explosion in 11.6W-16H stope was discussed and its history of such occurrences. B. Thompson of Dupont of Canada made the following comments after observations of our blasting practises in 16H stope. The plug that we are now using does not appear to be adequate enough to confine the explosive for the time required for it to do mechanical work (fragmentation) to its full potential. Instead, in B. Thompson's opinion, the plug is being fired into the open stope too quickly and the explosive reaction is being partially converted into chemical work (heat & flame). The resulting flame will ignite the fine pyritic dust suspended in the open stope thereby initiating the sulphide blast. Also, in Mr. Thompson's opinion, the practice of hanging a bag of lime into the open stope through the slot raise and dispersing it with a high energy primer cordet may actually be conducive to initiating a sulphide blast. The cordet 1 lb. primer will produce a flame that could ignite the sulphide dust. Additionally, Mr. Thompson pointed out, although lime is a flame depressant, common rock salt NaCl will absorb four times more heat than an equal amount of lime. Since the type of rock in 16H is very brittle it does not appear to require the 10' x 15' pattern of 6½" holes as drilled. However, to avoid changing too many variables it would be better to vary the density of the explosive rather than the hole pattern. This can be done by adding rock salt to the Anfo thereby not only reducing the powder density but also benefiting from the additional flame depressant characteristic of the salt. Mr. Thompson referred us to P. Blakney of TexasGulf for further information on the use of NaCl. Finally, we were advised, as an extra safety precaution, on large blasts that are time consuming to load, all MS delay connectors in the drift should be covered with sandbags to avoid accidental detonation from loose falling onto the connectors.

After discussion of the recommendations presented the following changes in practice wre accepted for 6½" blasting.

1. -The wooden plug will be secured approx. 3 ft. from the B.T. of the 6½" hole into the stope.

   -4-5 ft. of lime will be used as stemming below the charge.

   -8 ft. of a 75% nilite - 25% sodium chloride mixture will be charged followed by up to 13 ft. of nilite and the 1 lb. primer. (see drawing).

   -6 ft. of lime will then be used as stemming above the charge.

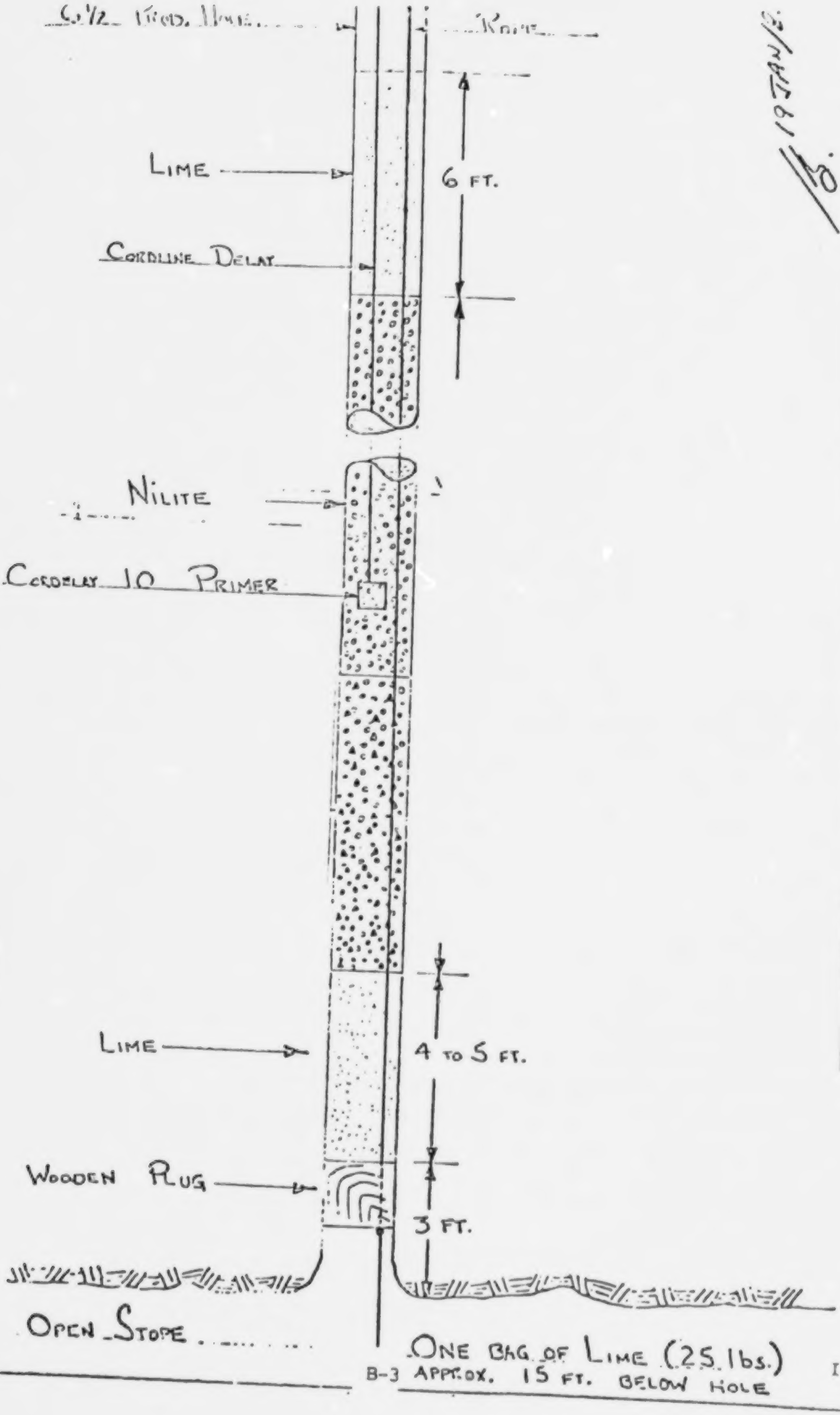
2. The use of cordet primers for dispersing lime prior to the blast will be discontinued immediately. One stick or trimtex will be substituted for dispersing the lime.

3. MS Delay connectors are to be covered with a small sandbag when hooked up and exposed to possible rock fall from the back of walls of the heading.

Our objective is to eliminate the occurence of sulphide blasts. It is anticipated that items 1. & 2. above will contribute to this end. However, additional effort is required in wetting down the muck, using atomizers and improving the stope ventilation on an ongoing basis. All future sulphide explosions must be thoroughly investigated so that further revisions to our practices can be made until we eliminate the causes of sulphide explosions.

DBO

DBO/ich
Attach.


6 1/2 Prod. Hole
Rope
Lime
6 FT.
Cordline Delay
Nilite
Cordelay 10 Primer
Lime
4 to 5 FT.
Wooden Plug
3 FT.
Open Stope
One Bag of Lime (25 lbs.)
Approx. 15 FT. Below Hole
B-3

/B. 19 JAN/8.

SHERRITT GORDON MINES LIMITED
Leaf Rapids, Manitoba, Canada R0B 1W0

STANDARD LOADING PRACTICE FOR
6 1/2" PRODUCTION HOLES

Scale: N.T.S.
Date: January 19[illegible]

I/5.(B-3)35

COPY

SHERRITT GORDON MINES LIMITED
Mining and Milling Division

INTER-OFFICE LETTER

Date: December 17, 1980

To: H. Repay

From: C. Bellingham

COPIES TO

PHG
DBO
EK
AM

WHEN FEASIBLE CONFINE LETTER TO ONE SUBJECT

RE: GENERAL PRECAUTIONS TO BE TAKEN FOR U/G BLASTING TO PREVENT SULPHIDE EXPLOSIONS

1. General precautions for all blasting areas:
   - a) Wet down walls and muck piles
   - b) Do not use aluminized explosives
   - c) Use atomizers where possible, and specifically for production blasts.
2. Development Headings (both drifts and raises)

   On drift rounds, drill cut holes at a minus angle and fill reamed holes with water. Hang a 10 lb. bag of lime in front of the cut so that lime dust and water dispersed with cut blast.

   On raise rounds hang both a bag of water and a bag of lime below and in line with the cut.
3. Production Blasts (2″ holes)

   Place a bag of lime between the 1st and 2nd row of rings to be blasted in each heading being blasted. The lime bags to be blasted simultaneously with a zero cap and primer followed by the production blast.

   Atomizers are to be used on each heading that accesses the stope. Atomizers to be activated just prior to blast and deactivated by oncoming shift after blast.

4. Production Blasts ($6\frac{1}{2}''$ holes)

For breakthrough holes, plug bottom breakthrough with wooden plug. Lower bag of lime onto plug charge hole with nilite or tovex LD to required depth including primer. Stem hole a maximum of 6 ft. with lime.

Lower a bag of lime down an adjacent empty hole charge with a primer and zero cap. A minimum of 1 bag per row is required.

Keep duration time of blast under 200 milli seconds.

Atomizers are to be used on each heading that access the stope. As per 3. above.

5. Secondary Blasts–Pole Blast in Drawpoint

Lime and water bags should be placed close to pole blast so that they are dispersed with blast. Use second pole to place lime and water bags as close to pole charge as possible.

6. Secondary Blasts (blockholes)

- Wet down area prior to loading.
- Do not overload holes.
- Hand lime&water bag in blasting chamber and detonate prior to blockhole charges.

C. Bellingham

CB/ih

SHERRITT GORDON MINES LIMITED

[illegible]

INTER-OFFICE LETTER

DATE February 5, 1979

COPIES TO
RCMcC / EDuR

TO C. Bellingham
Chief Engineer, Ruttan Mine

FROM: C.P. Brown
Chief Engineer, Fox Mine

WHEN FEASIBLE, CONFINE LETTER TO ONE SUBJECT

RE

SULPHIDE EXPLOSION

Please find enclosed, a description of the blast which caused the sulphide explosion, and also a plan of the 200 level, showing the extent of the related damage.

Since then there have been five blasts from surface in the 4-5 stope which have caused no sulphide explosions.

Several precautions have been taken:

1. Pulverized lime is now used as stemming below the powder column.
2. Lime, bagged in lay-flat tubing, is suspended in an unused hole just below the B.T. elevation.
3. Lime is spread around the access drifts to the 4-5 stope on 200 and 300 levels.
4. Water sprays are turned on prior to blasting in order to keep dust down.

I trust this information will be of value in case you encounter sulphide explosions with your upcoming stope blasts.

C. P. Brown

C.P. Brown

CPB/gl
encl.

January 29, 1979

C.P. Brown
Chief Engineer

RCMcC / EBuR
GCK

E. Kardas
Blasthole Engineer

4-5 STOPE BLAST NO. 11 FROM SURFACE

DATE BLASTED: January 25, 1979

TIME: 4:30 p.m.

NO. OF HOLES BLASTED: 24, 6-1/2" ø

TONS OF ORE BLASTED: 6,958

POWDER USED: 3,784 lb. AN/FO
330 lb. Hydromex M210 U

POWDER FACTOR: .59 lb./ton

LOADING:

Each hole contained 165 pounds of AN/FO and 14 pounds of Hydromex. Each hole was shot on a separate delay, using short-period electric blasting caps. Delays used were No. 1 to No. 15 and No. 17 to No. 25.

A wooden plug was placed six feet above breakthrough in each hole. Approximately two to three pounds of dry drill cuttings (dust) were placed in a burlap bag and then into a plastic bag. This was dropped on top of the plug. Two shovelfuls of drill cuttings (dust) were placed on top of this. Half a bag of Hydromex (14 pounds) was well slit and dropped on top. Two bags of AN/FO (110 pounds) were poured on top. The 1 pound Procore primer was lowered on a primacord, then another bag of AN/FO (55 pounds) was poured down the hole. Six feet of drill cuttings (dust) was shovelled on top of the powder column as stemming.

///cont'd///

REMARKS:

This method is basically the same as that used in the forty-two blasts carried out on 200 level in 4-5 stope. The only differences are that:

(a) One hundred eighty pounds of explosives per hole is now used, instead of 345 pounds as on 200 level.

(b) The drill cuttings used on 200 level were sulphides, but were moist and coarser. The drill cuttings used on surface are mostly sulphide dust from the dust collector used with the down-the-hole machine. This dust is extremely dry and fine.

(c) Sulphide blasts were evident in the seven blasts which were required to take out the slot area (fired with Hydromex, using the vertical crater retreat method). However, the previous slashes using AN/FO had not caused a secondary suphide blast. Blast No. 6 used 2,996 pounds of powder in 18 holes, of which 2,753 pounds was AN/FO and 243 pounds was Hydromex. No sulphide explosion was experienced.

EXPLOSIVE DUST (SULPHIDE BLASTS):

A dust explosion consists of a sudden pressure rise caused by the very rapid combustion of air-borne dust. Dust from sulphide ore is combustible when air-borne. Dusts less than 10 microns in size have no significant weight or inertia and hence can remain suspended indefinitely in an atmosphere.

Hydromex has a velocity of detonation of 16,200 ft./sec. AN/FO, when gravity loaded, has a velocity of 11,000 ft./sec.

The heat generated by the Hydromex and/or AMEX sets off the sulphide dust.

From talks with C.I.L. reps we have discovered that sulphide blasts have occurred while blasting 2" Ø holes at Snow Lake. They have since corrected the problem by installing atomizers on all sublevels leading into the stopes. INCO has had one large sulphide blast which occurred when they blasted a crown pillar into a stope that had sat dormant for quite a while and was extremely dry. Since then they have used atomizers and Hydromex T-3 rather than Hydromex M-210. At one mine in Quebec, calcium chloride is scattered about the drifts to prevent sulphide explosions.

///cont'd///

RECOMMENDATIONS:

1. The drill cuttings (dust) being used to seal the bottom of the hole should be replaced with sand from the outside gravel pile. Hydromex sitting on the fine dust at the bottom of the hole could be enough to set off the sulphide blast. Lime should also be used on the bottom as this would help to neutralize the sulphide explosion.

2. Atomizers (a mixture of fine water spray and air) should be installed at all openings on 200 level. This removes dusts from an airstream by coagulation and impingement. It would also dampen settled dust in the stope.

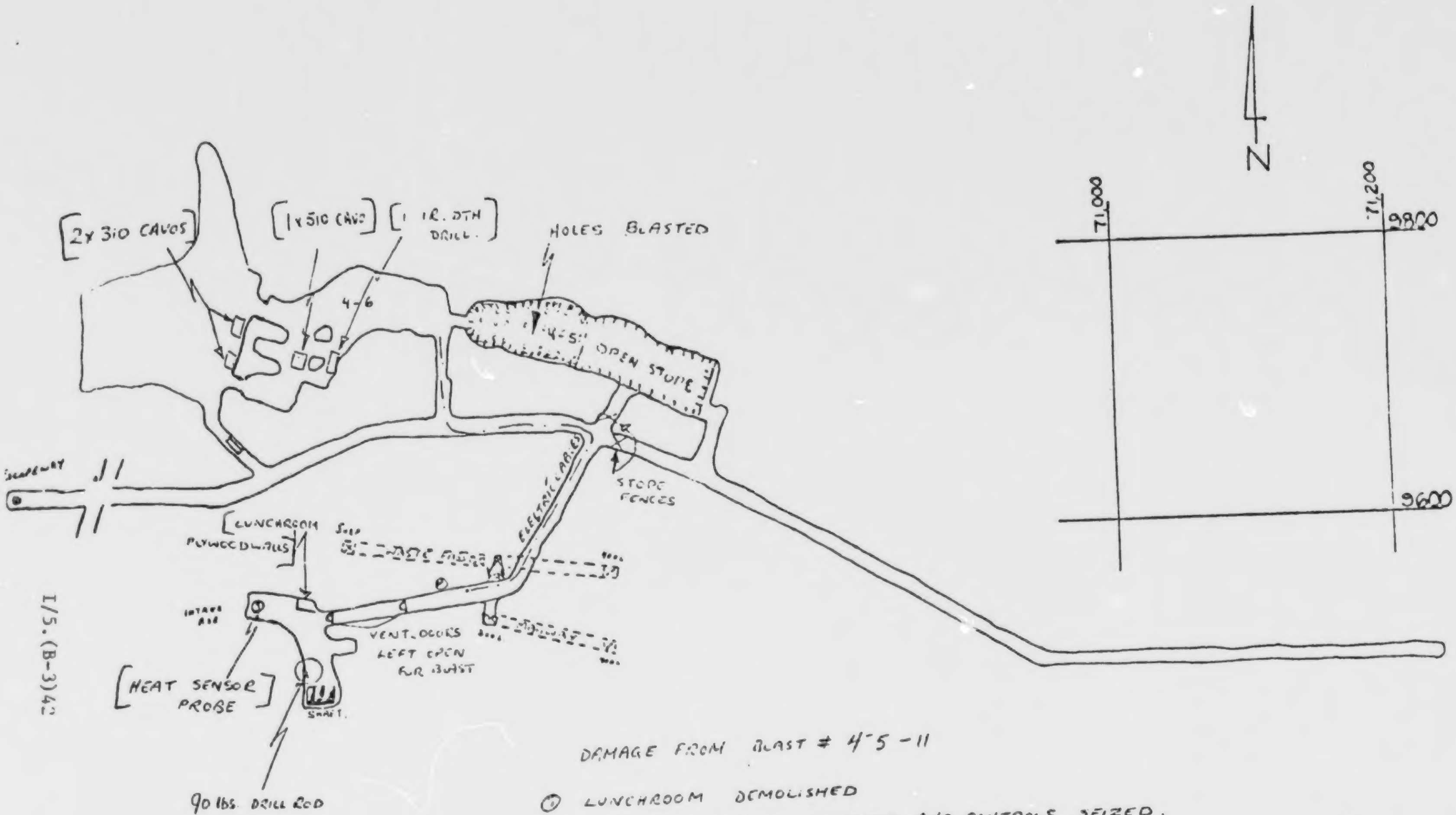
3. The stemming on top of the powder columns is ejected immediately with the blast and it is doubtful whether this contributes to the sulphide explosions. Water stemming can be used in taking out the slot area with Hydromex, however, when AN/FO is in use, water stemming would have to be placed in plastic, lay-flat tubing and lowered down the hole. Experience has shown that this tubing tears easily.

4. The access drifts to the 4-5 stoping area, on 200 level and 300 level, should be washed down and sprinkled with lime.

5. With our dust monitor, tests can be made to determine the dust content in the air before the atomizers are installed, and again after the atomizers have been in operation for a while. The atmosphere can be checked before a blast to determine the dust content. The monitor we have measures particles of 10 microns and less.

E. Kardas

EK/gl


N
71,000
71,200
9800
9600
2x 310 CAVOS
1x 510 CAVO
1 IR. DTH DRILL.
4-6
HOLES BLASTED
4-5 OPEN STOPE
STOPE FENCES
ELECTRIC CABLES
SLIPEWAY
LUNCHROOM PLYWOOD WALLS
SKIP
INTAKE AIR
VENT. DOORS LEFT OPEN FOR BLAST
HEAT SENSOR PROBE
SHAFT.
90 lbs. DRILL ROD

DAMAGE FROM BLAST # 4-5-11

① LUNCHROOM DEMOLISHED
② AIR HOSES ON CAVOS SCORCHED AND CONTROLS SEIZED.
③ PLASTIC COVERING ON ELECTRIC CABLES MELTED AND BURNT.
④ HEAT SENSOR PROBE BROKEN AND MISSING.
⑤ 90 lbs. DRILL ROD SMASHED INTO SKIP COMPARTMENT.
⑥ STOPE FENCES DEMOLISHED.
⑦ ROPES AROUND 4-5 STOPE BURNT.

2.00 LEVEL

QUESTIONNAIRE

SECONDARY DUST EXPLOSIONS IN SULPHIDE ORE MINING

1. Have you or your company any experience or knowledge on the above topic?

SOME Yes ______ No

2. If "YES", whom may I contact for further information?

ALEX WEBSTER Yourself or ______

3. Please attach or enclose any readily-available information such as:

- REFERENCES ______
- OTHER SOURCES ______
- COMMENTS I HAVE ATTACHED A LETTER FOR OUR DU PONT OPERATION IN AUSTRALIA. THERE MAY BE MORE IDEAS THAT CAN BE DISCUSSED AT GECO IN OCTOBER OR BY PHONE SOONER.

Please return this page to the undersigned at your earliest convenience, and thank you for help.

Name and title of respondent:
ALEX WEBSTER, P.ENG
TECHNICAL SPECIALIST
EXPLOSIVES DIVISION
Telephone: (705) 472-1300

Return to:
Mr. K.G. Wheeland
Head, Environmental Technology
NORANDA RESEARCH CENTRE
240 Hymus Boulevard
Pointe Claire, Quebec, Canada
H9R 1G5

DU PONT

DU PONT (AUSTRALIA) LTD.
INCORPORATED IN NEW SOUTH WALES
NORTHSIDE GARDENS, 168 WALKER STREET
P O BOX 930, NORTH SYDNEY
N S W 2060 AUSTRALIA
TELEPHONE (02) 923 6111
FACSIMILE (02) 929 7217 TELEX AA20685

June 12, 1986

Mr. Ben Guerin,
Nippising Works,
North Bay,
CANADA

Dear Sir,

In response to your telex, the work we have done here on sulphide dust explosives was carried out in the Cobar area in two mines.

One a copper lead zinc mine and the other a lead zinc operation. At both mines the sulphide content is very fine grained. The major ore types at EZ Elura Pyritic phyrothic formations.

EZ had several minor dust explosions in development headings and one major stope explosion that did $500M worth of equipment damage.

The major points we have learnt from their operations are:

1) Water sprays are at best ineffective. We found we must generate a water fog (e.g. a very fine suspension of water droplets).

2) Limestone dust is used as stemming in development ends and at the tops and bottoms of long holes in stope firings.

3) Delay periods must be kept as short as possible. In development headings interperiod delays do not exceed 150m sec. In fact most development faces are shot using millisecond delays.

   Stope firings are kept at a max of 35msec delay between holes or decks.

4) In stope firings sufficient time must be given prior to firing to allow the stope to fill with the water fog. Normally at least 1 hour.

   In some stopes a fog nozzle (firefighting nozzle) was suspended in the stope for added security but this is very expensive as you usually destroy it.

* DU PONT REGISTERED TRADEMARK

We did some work in both development headings and stope firings where we left out the limestone without any problems.

We also tried several firings using limestone and no water fog. Results dust explosion 3 out of 4 trials.

We also used water sprays instead of fog in some headings and in most cases had small dust explosions.

The conclusion we drew from the above was that a very fine dispersion of water droplets (.e.g. fog was the most efficient method of suppressing dust explosions in conjunction with shortest practical delay sequences.

Current practice is to use both Limestone dust in the holes or as stemming with a water fog. In development headings the walls are wet down with a hose for a distance of 50yds back from the face.

Attached are some sketches that may help you.

If you need more information please contact the writer.

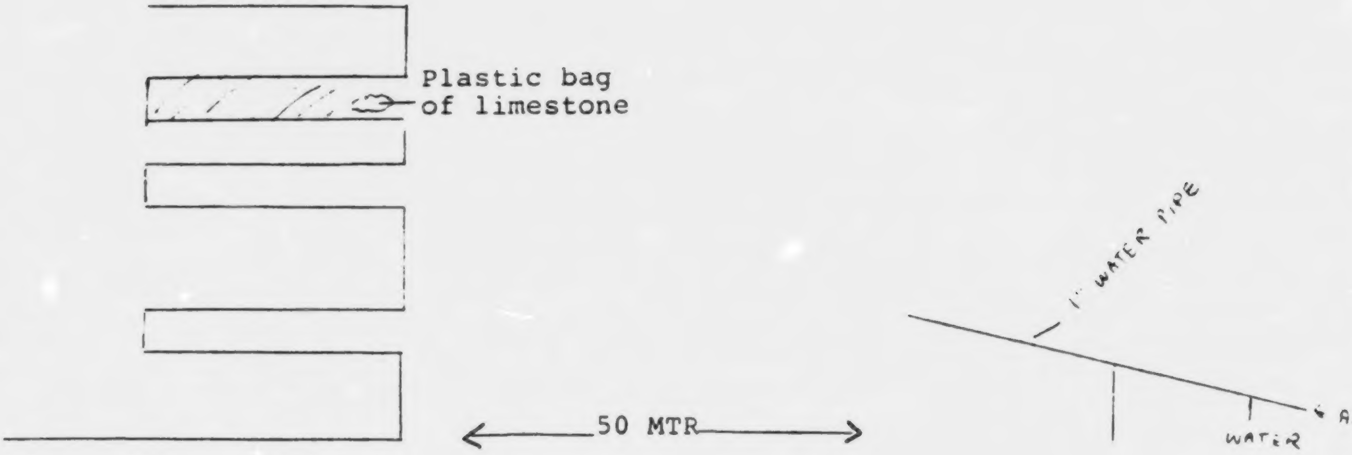
Yours sincerely,

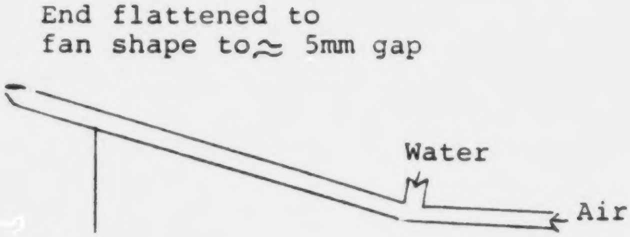
L.J. HYDE
TECHNICAL ENGINEER
MANUFACTURING DEPARTMENT
DU PONT (AUSTRALIA) LTD.

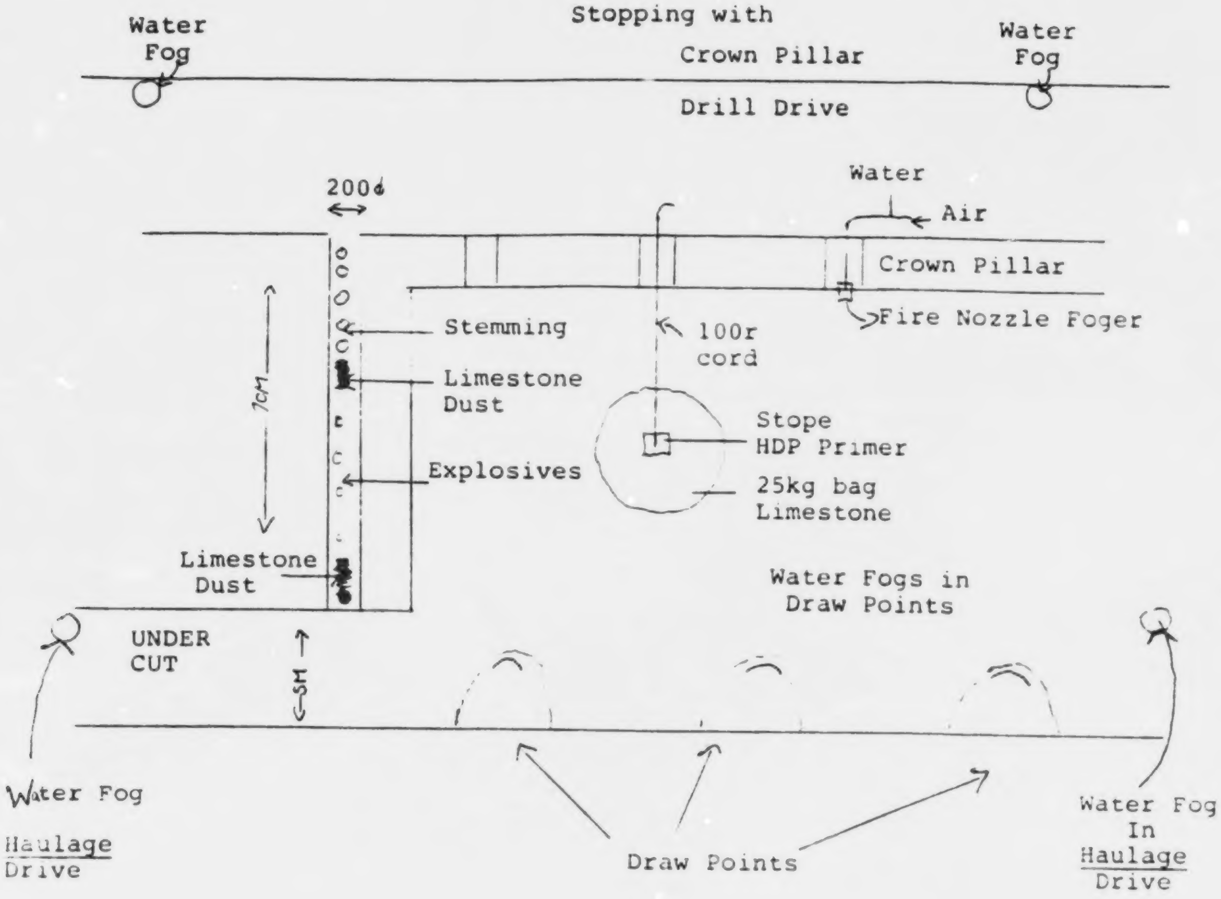
LJH:PLG

ATTACH.

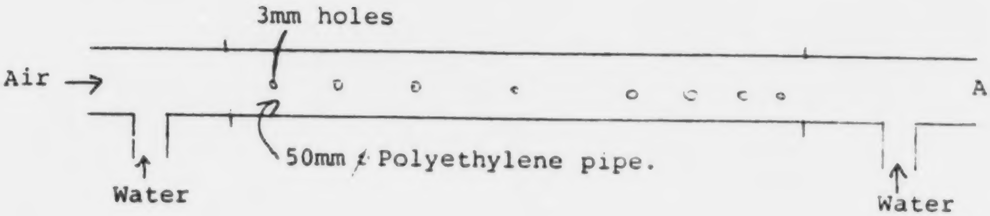
DEVELOPMENT HEADING


Plastic bag
of limestone
50 MTR
1" WATER PIPE
A
WATER

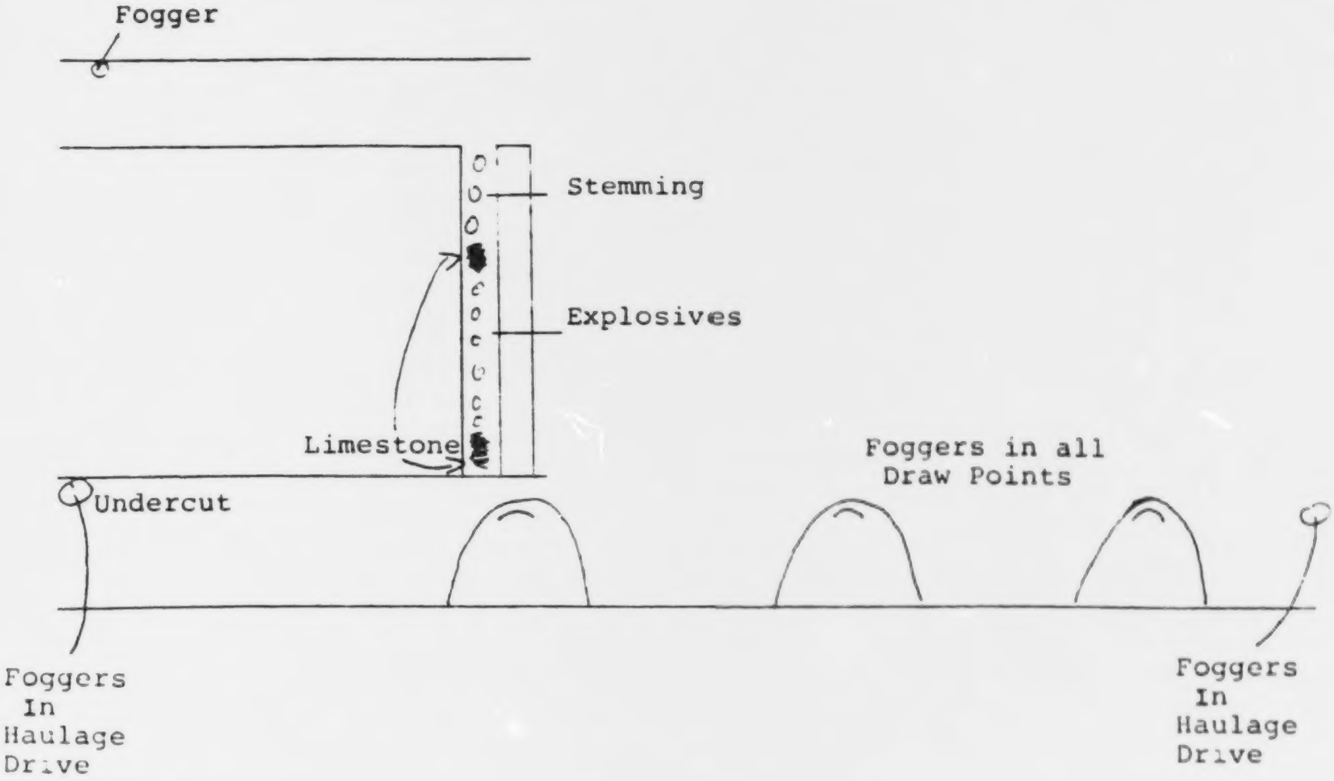

End flattened to
fan shape to ≈ 5mm gap
Water
Air


Water Fog
Stopping with
Crown Pillar
Water Fog
Drill Drive
200ɸ
Water
Air
Crown Pillar
Fire Nozzle Foger
Stemming
100r cord
7CM
Limestone Dust
Stope HDP Primer
Explosives
25kg bag Limestone
Limestone Dust
Water Fogs in Draw Points
UNDER CUT
5M
Water Fog
Haulage Drive
Draw Points
Water Fog In Haulage Drive

WATER FOGER DESCRIPTION


3mm holes
Air
Air
Water
50mm ɸ Polyethylene pipe.
Water

RETREAT STOPPING


Fogger
Stemming
Explosives
Limestone
Undercut
Foggers in all Draw Points
Foggers In Haulage Drive
Foggers In Haulage Drive

The key to getting the foggers to work well is to have high air flow rates to fully atomise the water.

PART II

Technical Presentations by Prof. R.J. Enright

University of Sydney, Australia

LIST OF TOPICS

DR. R.J. ENRIGHT

HEAD - MINING ENGINEERING

UNIVERSITY OF SYDNEY

AUSTRALIA

SULPHIDE DUST EXPLOSION CONFERENCE

THURSDAY OCTOBER 23, 1986 10:20 A.M.

DR R.J. ENRIGHT - HEAD, MINING ENGINEERING

UNIVERSITY OF SYDNEY

AUSTRALIA

Preambles

Dr. Enright will present case histories of dust explosions including: -

a) Three severe explosions at Cohan Mines, NSW, Australia

b) One explosion at Boleden, Sweden

c) Statistics on reporting explosions in stope blasts, development headings, and secondary blasts.

d) Toxicology

12 NOON LUNCH

SULPHIDE DUST EXPLOSION CONFERENCE

THURSDAY OCTOBER 23, 1986 1:00 P.M.

DR R.J. ENRIGHT - HEAD, MINING ENGINEERING

UNIVERSITY OF SYDNEY AUSTRALIA

Text

I Variables which influence the explosibility of a dust
  a) Chemical compositons
  b) particle size and distribution (e.g. does FeS_2 produce fines more readily than gangue mineral?)
  c) Dust concentration
  d) Ignition energy
  e) Addition of inert materials; limestone, moisture
  f) Spatial characteristics

II Development of dust explosions
  a) Primary dust explosions
  b) Secondary dust explosions

III Laboratory tests on dust explosibility and their applicability to mining conditions.
  a) Lab tests and parameters derived
  b) Incorrect conclusions by various researchers
  c) Details of experimental results on addition of limestone
  d) Details of experimental results on addition of water
  e) From laboratory to underground mining
  f) Techniques available, after an underground explosion, to determine the path and violence of the explosion
    i) magnetic; ii) microscopic; iii) S.E.M.

IV Proposed theory on the development of sulphide dust explosions
  a) Stopes
  b) Development headings

4:30 - 5:00 P.M. OPEN DISCUSSION - QUESTIONS

SULPHIDE DUST EXPLOSION CONFERENCE

FRIDAY OCTOBER 24, 1986 9:30

DR R.J. ENRIGHT - HEAD, MINING ENGINEERING

UNIVERSITY OF SYDNEY AUSTRALIA

Text (cont.)

V) Sulphide Dust
  a) residual dust thrown up
  b) borehole blasting
  c) collision of rock particles

VI) Ignition Sources
  a) primacord
  b) effect of delay intervals
  c) type of explosives (why do some types of explosives tend to be associated with more frequent dust explosions)

VII) Prevention of Dust Explosions
  a) Limestone (how much, when and where placed)
  b) Water - washing down, sprays and foggers

VIII) Inhibition of Dust Explosion
  a) Passive and triggered barriers
  b) foggers

IX) Effects of Dust Explosion
  a) Flame front
  b) SO2, and H2S

X) Safety
  a) Evacuate mine prior to blasting
  b) Men in underground refuge bay
  c) Men underground with S.C.S.R.

12:00 NOON LUNCH

ELURA MINE, COBAR, N.S.W. AUSTRALIA

The Elura Mine is a comparatively new mine with an annual production of around 1 million tonnes. Production is from large open stopes with 200 m.m. diameter blast holes around 50 m in depth.

The main mineral constituents are pyrite, ansenopyrite, pyrrhotite, sphalerite and galena. Typical ore analyses are:

Sulphur	30 - 37%
Iron	24 - 30%
Zinc	9 - 13%
Lead	5 - 9%
Silica	0 - 23%

Major sulphide dust explosions have occurred on:

30th November 1983
13th March 1984
28th October 1985

No personnel were injured in the explosions as the mine was evacuated prior to stope blasting. Extensive damage to equipment occurred during the 1983 explosions and to a lesser extent in the 1984 and 1985 explosions. Following each explosion a considerable time was required to clear the mine of sulphur dioxide fumes. It was obvious at the times of explosions that if any personnel had been present underground without adequate self contained breathing equipment then they would have been in a dangerous environment.

NOVEMBER 1983 Dust Explosion in Stope 2/6

Two stope blasts were carried out at the end of the shift. Stope 2/2, around 100 m north of Stope 2/6, was fired between 275 ms and 674 ms past zero time.

Only one hole was fired in Stope 2/6. The bottom deck was fired just after 634 ms and the blast duration was 175 ms.

The bottom charge was 339 kg of Tovex extra and 558 kg of Anfo was distributed in the 3 upper decks.

Top stemming was 200 m.m. lime, 3.6 m sand, 200 m.m. lime.

In addition to the 2 stope blasts 3 development headings were fired on 3 - Drill level between 450 and 1050 ms past zero time.

MARCH 1984 No details available of dust explosion.

OCTOBER 1985 Dust explosion in Stope 3/10

Following blasting at 7:40 a.m. on Monday 28th October 1985, a sulphide dust explosion was experienced.

The blast consisted of 30 secondary breaking "pops", a stope blast in 3/10 Stope, and a development heading.

The pops were initiated with two instantaneous detonators connected to 10gm Primacord. 22mm Powergel was used in the holes.

The stope blast consisted of 4 holes and a total of 300 kg Watergel and 2150 kg of Anfo were used for the blasts. The total blast duration was 200 ms. Two holes were loaded form the No. 2 haulage level,(one hole had been loaded on 22nd of October but not fired) and 2 holes on the No. 3 drill level. Five meters of stemming were used in the hole collars with 400 mm of limestone. The blast hole diameters were 200 mm and the depths vaned between 15 and 43 m.

Extensive evidence of the flame front and shock waves on the No. 3 Drill level and to a lesser degree on the No. 3 haulage level.

LANGSELE MINE

A severe sulphide dust explosion occurred at the Langsele Mine on 23rd May 1969. Two miners were killed and extensive damage caused on the 160, 210 and 260 m levels.

Productions commenced in 1956 and at the time of the accident a total of 450,000 tonnes per year was produced using sub-level stoping. In 1970 cut-and-fill mining was introduced on the 360 m level and sub-level stoping ceased in 1975.

The complex pyrite ore has the following average anaylsis:

Cu	0.85%
Pb	0.10%
Zn	3.84%
S	38.7%

DUST EXPLOSION

A sub-level stope with holes loaded from the 176, 210, 232 and 250 levels was fired on the 13th May 1969. The 45 mm diameter holes had been loaded with ANFO (prills) and dynamite primers. All holes on the 210 and 232 levels and one third of the holes on the 176 level mis-fired. An attempt was made to fire the remaining holes in the 14th but only half of the holes detonated. The remaining holes containing 800 kg of ANFO were checked and prepared for firing at the end of afternoon shift on the 23rd of May. The main blast was to be initiated on the 210 level plat and the two miners involved were then to travel to the 260 level to fire a raise. The cage was positioned at the 210 level. The mine had been evacuated except for the two shot-firers.

The following account if from Forman Bergkirst's report. " I listened to the sub-level benching blast (from near the headframe) and determined that the blast had gone well. Soon after there was heard a hurricane like sound, then sulphur smelling smoke, small stones and dust blown through the shaft. Several men were required to open.the hoist room door and help the driver out. The intense blowing throughout the shaft continued for about 3 minutes."

Bergkirst put on a pneumatic mask ordered the hoist driver to do the same in order to stay in the hoist room and proceeded via the ladder to the 210 m level. There he found the 2 miners lying lifeless in the cage. the cage was raised to the surface where the men were declared dead.

Extensive damage and evidence of the flame front was found on the 160, 210 and 260 m levels.

CURRENT SULPHIDE DUST EXPLOSIONS

Sulphur dust explosions are a fairly common occurrence at the Langsele and Kristenberg Mines (22-27% total suffered). The explosions are associated with development and production (cut-and-fill) blasting.

SOME INCOMPLETE SULPHIDE DUST EXPLOSION STATISTICS

The following statistics are nowhere near complete. Very few sulphide dust explosions are reported in the literature.

YEAR	MINE	LOCATION
1985	Geco	stoping
1985	Elura	stoping
1984	Elura	stoping
1983	Elura	stoping
1982	Mattabi	stoping
1978	Fox	VCR
1978	Brunswick	Stoping
1974	Prieska	stoping
1974	Prieska	stoping
1974	Prieska	stoping
1969	Langsele	stoping
1926	U.S.A.	sprung churn drill hole
1924	U.S.A.	stoping
1924	U.S.A.	stoping
1986	Langsele	driving
1986	Kristenberg	driving
1981	Lyon Lake	driving
1978	Ruttan	driving
1974	Prieska	development
1970	Fox	driving
1970	fox	driving
1924	U.S.A.	development
1981	Mattabi	secondary blasting drawpoint
1978	Fox	secondary blasting drawpoint
1978	Fox	secondary blasting drawpoint

SUMMARY OF EXPLOSIONS

14 explosions related to Stope Blasting
8 explosions related to Development
3 explosions related to Secondary Blasting

SUMMARY OF FATALITIES AND INJURIES

DATE	COUNTRY	FATALITIES	INJURIES
1985	Canada	1(SO2)	2(SO2)
1969	Sweden	2(SO2)	-
1915-1958	Sweden	-	3(SO2)
1926	U.S.A.	3(burns)	1(burns)
1924	U.S.A.	2(SO2)	1(SO2)
1924	U.S.A.	1(SO2)	1(SO2)
1924	U.S.A.	1(SO2)	6(SO2)
		10 ==	14 ==

DRAFT ONLY

TOXICOLOGY OF SUPHUR DIOXIDE, HYDROGEN SULPHIDE AND CARBON MONOXIDE

Sulphur dioxide

The gas can be detected by the average individual at 3 ppm and concentrations of 6 to 12 ppm cause immediate irritation to the nose and throat. The gas is dangerous to the eyes as it causes irritation and inflamation of the conjuntiva. A concentration of 20 ppm is the least amount which is irritating to the eyes.

Sulphur dioxide affects the upper respiratory tract and the bronchi. It may cause edema of the lungs or glottis, and can produce respiratory paralysis. The gas is so irritating that it provides its own warning of toxic concentrations. A concentration of 400 to 500 ppm is immediately dangerous to life and 50 to 100 ppm is considered to be the maximum permissible concentration for exposures of 30 to 60 minutes. Less than fatal concentrations can be borne for fair periods of time with no apparent permanent damage. The toxicity of sulphur dioxide is comparable to that of hydrogen chloride.

Hydrogen sulphide

With higher concentrations the action of the gas on the nervous system becomes more prominent, and a 30-minute exposure to 500 ppm results in headache, dizziness, excitement, staggering gait and dysuria, followed sometimes by bronchitis or bronchopneumonia. The action on the nervous system is, with samll amounts, one of depression; in larger amounts, it stimulates, and with very high amounts of 800 to 1000 ppm may be fatal in 30 minutes, and higher concentrations are instantly fatal. Fatal hydrogen sulphide poisoning may occur even more rapidly than that following exposure to a similar concentration of hydrogen cyanide. Hydrogen sulphide does not combine with the hemoglobin of the blood; its asphyxiant action is due to paralysis of the respiratory center.

Carbon Monoxide

Carbon monoxide has an affinity for hemoglobin 210 times that of oxygen, and by combining with the hemoglobin, renders the latter incapable of carrying oxygen to the tissues. The effect on the body is therefore predominantly one of asphyxia. In addition to this action, the presence of CO - hemoglobin in the blood interfers with the dissociation of the remaining oxyhemoglobin, so that tissues are further deprived of oxygen.

A concentration of 400 to 500 ppm in the air can be inhaled without appreciable effect for 1 hour. A concentration of 1,000 to 2,000 ppm is dangerous and concentrations of 4,000 ppm and over are fatal in less than an hour. Carbon monoxide is considered to be particularly dangerous as it is almost impossible to detect by smell or taste.

PHYSICAL PROPERTIES OF SO_2, H_2S, CO

Table 1

	SO_2	H_2S	CO
Mol. Wgt.	64.06	34.08	28.01
Specific gravity[1]	2.264	1.189	0.968
Colour	Colourless	Colourless	Colourless
Odour	purgent, suffocating	Offensive	Odorless
Solubility in 100 parts	22.8 gram 0°C	437 cc @ 0°C	3.5 cc @ 0°C
ℓeℓ[2]	non-flammable	4.3	12.5%
ueℓ[3]	non-flammable	46	74.2%
autoignit. temp.		260°C	1204°C

Notes:

1. Specific gravity with reference to air = 1.0
2. Lower explosive limit
3. Upper explosive limit

Toxicology

The toxic effects of a gas are related to a number of factors including time exposed, gas concentration and work being performed. An individual will breathe around 5 ℓ/min at test, 20 ℓ/min with heavy exertion. High temperatures, humidity, exercise and emotional stress will tend to increase the breathing and heart rate.

Toxicity is the ability of a chemical molecule or compund to produce injury once it reaches a susceptible site in or on a body. Toxicity hazard is the probability that injury may be caused by the manner in which the substance is used. The toxic hazrd rating of sulphur dioxide, hydrogen sulphide and carbon monoxide based on data published by Sax et al. (1963) are given in Table 2. The following definitions apply to terms used in Table 2.

Acute - This term is used in the medical sense to mean "of short duration". It refers to a single exposure of a duration measured in seconds, minutes or hours when substances are inhaled or absorbed through the skin.

Chronic -This term is used in contrast to "acute" and means "of short duration". It refers to prolonged or repeated exposures of a duration measured in days, months or years. The term "chronic" does not refer to severety of symptons but carried the implication of exposures or doses which would be relatively hamless unless extended or repeated over long periods of time.

Local - This term refers to the site of action of an agent and means that the action takes place at the point or area of contact. The site may be skin, mucous membranes of the eyes, nose, mouth, throat or anywhere along the respiratory or gastrointestinal system. Absorption does not necessarily occur.

Systemic - This term refers to a site of action other than the point of contact and presupposes that absorption has taken place. A material is said to have been absorbed only when it has gained entry into the blood stream and consequently may be carried to all part of the body.

TOXIC HAZARD RATING OF SO_2, H_2S, CO

Table 2

	SO_2	H_2S	CO
Acute Local	irritant 3 inhaltion 3 ingestion 3	irritant 3 inhalation 3	0
Acute Systemic	U	inhalation 3	inhalation 3
Chronic local	irritant 2 inhalation 2	irritant 3	0
Chronic systemic	U	inhalation 3	inhalation 1

Toxic Hazard Rating Code

0 None:	(a) No harm under any conditions; (b) Harmful only under unusual conditions
1 Slight:	Causes readily reversible changed which disappear after end of exposure.
2 Moderate:	May involve both irreversible and reversible changes, not severe enough to cause death or premanent injury
3 High:	May cause death or permanent injury after very short exposure to small quantitites.
U Unknown:	No information on humans considered valid by authors.

ELURA 27/5/86

STANDARD PRACTICE

STANDARD PRACTICE PRIOR TO STOPE FIRING

1) Lime at top and bottom of each hole to be 400mm.

2) Stemming used above a deck of watergel is to be 3.8m.

3) E-Cord to be lowered with weight and any knot covered with lime.

4) Access ways at top and bottom of stopes to be washed down thoroughly.

5) Water to be sprayed into stope from hoses down rotary holes previously fired. Hose to be left running down rotary hole two rows in front of hole to be fired.

6) Air/Water sprays to be turned on fifteen minutes before blast, on both drill and haulage levels.

7) Main ventilation fans left running.

8) All equipment to be parked in designated areas.

9) No loose items or equipment to be left at plat areas.

10) All rollerdoors to be left open.

11) All blasting to be done from surface at end of shift except
    - * Firing passes and crusher feeder
    - * Stage II Development (waste only)

12) Blasting siren to be sounded for two minutes before initiating blast.

13) Headframe to be cleared of people and cage docked in position.

14) There will be no entry to the Mine after 3.30 pm, 11.30 pm and 7.30 am when firing on that shift, and the mine will be cleared at the end of each shift.

15) All drawpoint firing to be done at end of shift when people are out of the mine.

16) No rock popping to be done at the same time as long hole blasting in the same stope.

17) No blasting of two stopes close to each other in the same blast.

24.20.1 No person shall enter or be caused or permitted to enter the underground workings of any mine or works unless he is issued, free of charge, with a self rescuing device which shall be:

(a) kept on his person at all times while he is underground,

(b) in good condition and ready for instant use,

(c) of the self-contained type with a duration of 30 minutes at a ventilation rate of 30 litres per minute, and

(d) of a design and construction approved by the Government Mining Engineer.

24.20.2 The manager shall ensure that in the event of an explosion, fire or other emergency which may necessitate the use of self-rescuers, adequate and sufficient refuge bays or other safe places are provided so that any person in any part of the mine or works where he may have to travel or work will be able to reach such refuge bay or other safe place, without undue exertion, within the limit of protection afforded by his self-rescuer.

Such refuge bays or other safe places shall be:

(a) equipped with means for the reliable supply of breathable air, .

(b) equipped with means for the supply of potable water,

(c) supplied with adequate and suitable first aid equipment

(d) of sufficient size to accommodate the greatest number of persons likely to be in the area at any one time

(e) Capable of being sealed or to have alternative effective arrangements to prevent the entry of noxious gasses.

(f) equipped with a telephone or other means of communication with the surface,

(g) be constructed of fire resistant materials.

24.20.3 The manager shall draw up a code of practice for rescue operations, and he shall ensure that all persons who enter the underground workings of his mine or works are adequately trained in the use of self-rescuers, and in the drill necessary to ensure their own survival as far as possible in the event of an explosion, fire or other emergency.

Training in the correct use of self-rescuers shall be repeated at intervals not exceeding one year, and shall be given to all persons, who may have to go underground.

24.20.4 Regulations 24.20.1, 24.20.2 and 24.20.3 shall come into force on any specific mine or works, or any specific class or type of mine or works on a date specified in writing, by the Government Mining Engineer for that mine or works, or that class or type of mine or works.

Dust Explosions

SOUTH AFRICA

"Rules for the Prevention of an Explosion Arising out of Dust in the Mine Air.

1. Stope Blasting

1.1 All multiple shot firing shall be detonated electrically from an approved firing box on the surface of the mine and only after all personnel have vacated the underground workings.

1.2 The area of any blast and 50 feet on both intake and return air side shall be thoroughly watered down just prior to charging the holes for blasting.

1.3 Air-water sprays shall be installed on the air intake and return sides of the blast area, no closer than 50 feet or further than 150 feet from the extremities of the blast and turned on prior to firing so as to create a satisfactory water fog over the entire blast area.

1.4 Approved short delay detonation only shall be used at all times. The delay period between successive shot holes or rows of shot holes shall not exceed 35 to 40 m/s.

1.5 The size of stope firings shall be limited to 3,000 tons at any one time.

1.6 The explosives used shall be limited to AN 60 and AN/FO authorised by the Department of Mines or any other explosives sanctioned by The Chief Inspector from time to time. ✓ Tovex?

1.7 Where possible all inflammable material shall be removed from the blast area to a point outside the air-water spray zone.

1.8 All charged holes shall be stemmed to the collar with an approved substance such as limestone dust, except cut rounds and in raises where bags containing an adequate quantity of such substance shall be hung or located immediately adjacent to the collars of the charged holes.

2. Secondary Blasting or "Popping"

2.1 Not more than one shot shall be fired at any one time unless initiation is from the surface with all personnel out of the mine.

2.2 Single shot firings may take place during the shift provided the area is directly connected to an unmanned return airway. All accesses to the stope on return airway side shall be marked with danger tags or effectively blocked.

2.3 When firing except in eastern ore body stope each charge shall be stemmed with approved material such as limestone dust. Plaster shots shall be covered with an adequate quantity of limestone dust.

2.4 All secondary blasts fired shall be fired simultaneously using instantaneous type electric detonators only.

2.5 The blast area shall be watered down prior to firing and air-water sprays shall be used.

3. Development

Lateral

3.1 Firing of development headings less than 600 feet along the shortest route from the cribbing or plat assembly area shall only take place with all personnel removed from that level to a place of through ventilation.

3.3 Air-water sprays shall be used and located not closer than 50 feet nor further than 150 feet from the face.

3.4 All charged holes shall be stemmed with limestone dust or other approved material except charged holes in cut rounds, where a bag containing an adequate quantity of such approved material shall be hung immediately adjacent to the cut round.

3.5 As for 1.6.

3.6 As for 1.7.

Vertical or near vertical (within definition of Rise)

3.7 Firing of all development headings under this section less than 300 feet along the shortest route from the cribbing or plat assembly area shall only take place with all personnel removed from that level to a place of through ventilation.

3.8 Within the range of 300 to 450 feet from the cribbing place, firing of a rise face below a height of 50 feet shall take place only with all personnel removed from that Level to a place of through ventilation.

3.9 Within the range of 450 to 600 feet, any rise firing below a height of 30 feet shall only take place with all personnel removed from that level to a place of through ventilation.

3.10 Outside the above limits rise firing may take place at crib times and change of shift from the level of commencement plat.

3.11 As for 1.4.

3.12 Air-water sprays shall be used at the face for all firings.

3.13 As for 1.8.

3.14 As for 1.6.

3.15 All inflammable materials shall be removed from the area.

4. Special Development

For special development where it is obvious that there can be no possibility of mineralisation being encountered, the above procedures need not apply.

However, such special development localities shall be approved of by an Inspector.

5. Refiring of Misfires

Development

Refiring may be made during shift if the area is connected to an unmanned return airway and detonation is effected by instantaneous electric detonators, and holes shall be stemmed as for lateral development. If multiple shots are to be fired using a short delay method then procedures as for development shall apply.

Stopes

Single holes may be refired using stope procedures as for 2.
Multiple stope refirings shall be as for stope blasting.

6. General

Under these rules any dust explosion suspected, or any dust explosion experienced shall be deemed to fall within the provisions of General Rule 57(4) and shall be notified to an Inspector of Mines forthwith."

I VARIABLES WHICH INFLUENCE THE EXPLOSIBILITY OF A DUST

I(A) CHEMICAL COMPOSITION

The chemical composition of a dust has a most pronounced influence on the explosibility of dust - the percentage of reactive and non-ractive minerals

with coal dust	% Volatile matter % Fixed carbon % Ash % Moisture
with pyritic ore	% Pyrite % Other Sulphides % Gangue % moisture

Is pyrrhotite ore worse than pyrite ore?

The chemical composition of a dust can be changed by:

1. adding inert dusts
2. adding water

In a pyritic dust explosion typical reactions are:

3 -FeS2 + 8-02 -- Fe304 + 6-S02 + 2462 KJ/mol

4-FeS2 + 11-02 -- 2-Fe203 + 8-S02 + 3458 KJ/mol

Magnetite - Fe304
Hematite - Fe203

NOTE: the composition of a dust can be different from the ore composition as certain minerals tend to produce fines more readily than others.

I(B) PARTICLE SIZE DISTRIBUTION

- A decrease in particle size will result in an increase in explosiblity.
- dust, grit or powder ?

A reduction in particle size results in

1) increased surface area and reaction rate

2) decrease in minimum ignition energy

3) increase in dispersibility

4) decrease in settling velocity

I(C) DUST CONCENTRATION

- with gases and vapours well defined upper and lower explosive limits
- a dust is different as it occupies only a small part of the total volume
- a lower explosive level exists for dusts. This L.E.L. is not well defined as it depends on the experimental techniques. Usually around 50 - 100 g/m3.
- The upper explosive level is difficult to determine. The U.E.L. is certainly in excess of 2500 g/m3.

NOTE: Importance of dust origin - is is residual dust on roof and walls or formed during an explosion?

In a 4m x 3m drive a thickness of 0.6mm on the roof will produce a dust concentration of 500 g/m3.

I(D) IGNITION ENERGY

Minimum ignition temperature

Minimum ignition energy

In coal mines and grain industries the minimum ignition energy is an important consideration.

Concept of permitted explosive in coal mines.

In a metal mine large ignition occurs during blasting.

Possible ignition sources in metal mines
. hot gases
. burning undetonated explosives
. buring explosive particles
. missfires
. frictional ignition

II DEVELOPMENT OF DUST EXPLOSIONS

Need to distinguish between coal dust and sulphide dust explosions.

1. In a coal mine dust is produced continuously during mining and transportation. Air-borne dust settles outbye of the face and various transfer points.

2. Usual sequence of a coal dust explosion is a primary methane/air explosion and a secondary coal dust explosion.

3. As the explosion travels throughout the mine it increases in violence (if no protective measures taken).

4. Limestone dust is sprayed throughout the mine.

5. A sulphide dust explosion is ususally associated with the use of high explosives.

6. The dust cloud develops during blasting.

7. The primary sulphide dust explosion is usually the most violent.

III LABORATORY TESTS

IIIa Explosion Parameters determined experimentally

- Maximum pressure developed P(max)
- Maximum rate of pressure rise $\frac{(dp)}{dt}$
- P(max) and $\frac{dp}{dt}$ versus dust concentration
- Minimum ignition energy
- Minimum ignition temperature

IIIb Incorrect Conclusions From Experimental Data

The desired parameters depend on
- Shape and size of explosion chamber
- Method of dust dispersion
- Method of dust ignition (time and place).
- Ignition energy

Incorrect conclusions result due to the variability of the tests. A dust may be considered to be non-explosive if the ignition energy used in the test is too small.

- The dispersion techniques may not disperse the dust in the chamber and so dust is reported non-explosive etc.

IIIc ADDITION OF LIMESTONE AND OTHER INERT DUSTS TO PREVENT OR INHIBIT DUST EXPLOSIONS

Addition of an inert dust inhibits the development of an explosion by serveral different methods.

1. Combustion of coal or sulphide dust is retarded as portion of the heat of combustion is transferred to inert dust (0.05 KJ/kg for limestone)

2. Inert dust shields combustible dust from radiant energy.

3. Inert dust inhibits diffusion of oxygen to burning particles and restricts diffusion of gases from these particles.

4. Reaction $CACO3 -- CaO + CO2$ absorbs heat

5. Carbon dioxide may inhibit the explosion .

6. Increase in minimum ignition energy with addition of inert dust.

Around 80% incombustible content required to inert coal dust .

In NSW regulation state 75% incombustible content at face
65% throughout the mine

IIId ADDITION OF MOISTURE TO INHIBIT DUST EXPLOSIONS

The method by which free water, a distinct flow inherent moisture acts in reducing the explosibility of a coal dust is somewhat different from stone dust.

FREE WATER

1. Absorbs heat from the flame front due to:
    a) High Specific Heat 0.24 KJ/kg
    b) Heat of Vapourization 128.3 KJ/kg

2. Cohesion increases with moisture and agglomeration of the particles may occur.

    P(max) and $\frac{(dp)}{dt}$ decrease with an increase in particle size

3. Increase moisture content reduces the dispersibility of a dust. At high moisture contents a mud-like mixture may be formed.

NOTE: Ability of a dust to absorb moisture varies greatly between dusts.

4. Minimum ignition energy increased.

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INHIBITIONS OF SULFIDE DUST EXPLOSIONS WITH LIMESTONE

by

R.J. Enright[1]

ABSTRACT

The introduction of large diameter drill holes and mass firings in underground metalliferous mines has led to an increase in the number of reported sulfide dust explosions in Australia and overseas. Adaptation of the coal mining technique of using limestone to inhibit or prevent dust explosions has not been entirely successful as the development and inhibition of a sulfide dust explosion is somewhat different from that of a coal dust explosion. Tests were carried out on two pyritic ore samples, sulfur contents of 41 and 36 per cent, in 8 and 20 litre explosion chambers to evaluate the effect of the addition of limestone on the maximum explosive pressures developed and rates of pressure rise. Significant values were obtained in both chambers with dusts containing 60 per cent ore and 40 per cent limestone. The percentages of limestone required to inhibit the pyritic dusts were considerably higher than those values generally accepted by the mining industry and the current methods used to inhibit sulfide dust explosions should be re-evaluated.

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INHIBITION DES COUPS DE POUSSIÈRES SULFURÉES AVEC DU CALCAIRE

Par
R.J. Enright[1]

RÉSUMÉ

Le recours aux trous de mine de grand diamètre et aux tirs massifs dans des mines métallifères souterraines a conduit à une augmentation du nombre des coups de poussières sulfurées en Australie et outre-mer. L'adaptation de la technique d'inhibition par le calcaire employé dans les mines de charbon n'a pas tout le succès escompté car l'évolution et l'inhibition d'un coup de poussières sulfurées sont quelque peu différentes de ceux d'un coup de poussières de charbon. On a effectué des essais sur deux échantillons de minerai pyriteux, à teneurs en soufre de 41 et 36 %, dans des chambres d'explosion de 8 et 20 litres afin d'évaluer l'effet de l'addition de calcaire sur les pressions maximales d'explosion produites et sur les taux d'augmentation de pression. On a obtenu des valeurs significatives dans les deux chambres où les poussières contenaient 60 % de minerai et 40 % de calcaire. Les pourcentages de calcaire nécessaires pour inhiber les poussières pyriteuses étaient considérablement plus élevés que ceux généralement acceptés par l'industrie minière et les méthodes courantes utilisées pour inhiber les coups de poussières sulfurées devraient donc être réévaluées.

INTRODUCTION

Over the past decade there has been a significant increase in the number and severity of blast-induced sulfide dust explosions in the underground workings of massive sulfide deposits in Europe, Canada, South Africa and Australia. The majority of these dust explosions have occurred in open stopes using large diameter drill holes with bench blasting or the vertical retreat mining method, (Enright, 1984). However significant numbers of dust explosions have been associated with development headings and secondary blasting at draw points (Du Russell, 1981; Holding, 1975).

A dust explosion is essentially a very rapid combustion of a suspension of fine particles, during which heat is generated at a higher rate than is dissipated to the surroundings. This phenomenon is characterized by the sudden development of pressure and a flame front which frequently cause loss of life and extensive destruction of plant and equipment. The explosion leaves in its wake an atmosphere with reduced oxygen content and highly toxic gases. In a pyritic dust explosion the products of combustion are usually magnetite, Fe_3O_4, or hematite, Fe_2O_3, and sulfur dioxide. Typical reactions are:

$$3\ FeS_2 + 8\ O_2 = Fe_3O_4 + 6\ SO_2 + 2462\ \text{kJ/mol.}$$
$$4\ FeS_2 + 11\ O_2 = 2Fe_2O_3 + 8\ SO_2 + 3458\ \text{kJ/mol.}$$

Two methods used to prevent or inhibit sulfide dust explosions are the generation of air-water fogs during blasting and the application of limestone dust to inert the sulfide dust. In order to investigate the effectiveness of limestone as an inhibitor various limestone-pyritic ore dust mixtures were tested in two explosion chambers. Significant explosion pressures were observed in 8 and 20 litre chambers with mixtures containing 60 per cent pyritic ore and 40 per cent limestone.

FORMATION AND DEVELOPMENT OF A DUST EXPLOSION

A dust explosion occurs when the following four conditions are satisfied simultaneously:

1. A combustible solid in a finely divided state is dispersed in an oxidizing medium, usually air.
2. The concentration of the dispersed dust is within the explosible range.
3. An external source of ignition of sufficient energy to ignite the cloud is present.
4. A chemical reaction occurs in a confined space.

The development and severity of a dust explosion are a function of the chemical composition, size distribution, shape, surface area, density and concentration of the dust. Additional variables are the spatial characteristics of the enclosing space, degree of turbulence of the dust cloud, and the intensity and duration of the igniting source (Bartknecht, 1981). The chemical composition of a dust is important as an increase in combustible matter of the dust will increase its explosibility whereas an increase in the inert components or the addition of inert dust or water will decrease the dust explosibility.

In a coal mine the usual sequence in the development of a dust explosion is that a local ignition of a methane-air mixture causes a gas explosion and the pressure wave from the explosion disturbs dust from the roof, ribs and floor of the workings. The flame front associated with the gas explosion ignites the airborne dust and a secondary, and much more violent, self-sustaining dust explosion is produced. Defensive measures used in coal mines to prevent dust explosions include restrictions on the type and use of explosives, the elimination of ignition sources, ventilation to remove methane, and the application of water or inert dusts to reduce the explosibility of the coal dust. Limestone dust, sometimes referred to as stone dust, is used extensively in coal mines as it is an effective silica free inert material. The New South Wales Mines Regulation Act (N.S.W. Government, 1982) states that sufficient inert dust must be applied so as to ensure that the resulting mixture of coal and inert dust contains at least 75 per cent incombustible matter at the face workings and 65 per cent throughout the remainder of the mine.

The development of a sulfide dust explosion in a metalliferous mine is somewhat different to that of a coal dust explosion in a coal mine. Generation and ignition of the dust clouds are usually associated with the use of high explosives and the dust cloud may be produced by one or more of the following methods:

1. Detonation of explosives in a blast hole ejects a cloud of fine dust into the space around the hole.
2. Impact of blasted rock on the walls and floor of a stope.
3. Air blast, produced when the initial holes of a blasting pattern are detonated, may disturb dust lying on the roof, walls and floor of a stope.
4. Vibrations caused by blasting in nearby workings may disturb the dust on the roof and walls of an excavation so that a dust cloud is generated prior to blasting in the excavation.

For a dust explosion to occur the airborne dust must be exposed to an ignition source of sufficient temperature and duration to ignite the dust. Detonation of explosives during and after the formation of the cloud or the burning of undetonated explosives may provide ignition sources. Frictional ignition by pyritic ore is another possible, though less likely, ignition source. Missfires may lead to conditions where explosives may be ignited or detonated after the normal blast. The techniques developed to reduce blast vibrations, such as deck charging, air spacers, and vertical crater retreat mining may have led inadvertently to an increase in the risks of a dust explosion. The pressure wave and flame front-associated with the dust explosion may cause dust previously deposited on the back, walls and floor of nearby workings to develop into a self-sustaining secondary explosion.

Methods used to prevent sulfide dust explosions include washing of the roof and walls of excavations, use of air-water foggers to produce a mist in the space surrounding the blast, and the use of fine limestone dust as an explosion suppressant. In a coal mine dust is produced during the cutting or shearing of the coal seam and transportation of the coal and the air-borne dust setting outbye of the coal face. Limestone dust is sprayed on the headings so that if the coal-limestone dust mixture is raised by an air blast then this mixture will be non-explosive. In a metalliferous mine the bulk of the dust is produced during a blast and attempts are made to inert this dust by using limestone dust as deck spacing and stemming. Bags of limestone dust may be placed adjacent to the drill holes and dispersed with a small charge prior to the main blast. The roof and walls of comparatively small underground openings can be sprayed with limestone dust but this technique cannot be applied to a large stope or dangerous working area.

EXPERIMENTAL PROCEDURES

SAMPLE DESCRIPTION AND PREPARATION

Detailed experiments were carried out on two ore samples, 1 and 2, from and underground mine where dust explosions had occurred. A limited number of tests were made with two comparatively pure pyrite samples, 3 and 4. Microscopic examination of the ore samples indicated that the main mineral constituents were pyrite, pyrrhotite, sphalerite, galena and arsenopyrite. The samples were reduced to minus 5 mm in a laboratory jaw crusher and to minus 90 microns in a vibratory grinder. Analysis of the samples are given in Table 1. Mixtures of ore and limestone dust were prepared with the as received white commercial stone dust used in N.S.W. coal mines. Sieve analyses of the limestone dust indicated that 34 per cent was between 125 and 90 microns in size and 64 per cent less than 90 microns. The pyritic ore-limestone dust mixtures were prepared by alternate sieving, through a 180 micron screen, small quantities of ore and limestone and then resieving the combined mass of sample until a uniform mixture was obtained.

Table 1 - Ore sample analysis

Sample	No. 1	No. 2	No. 3	No. 4
Sulfur	41.4%	35.5%	52.0%	47.1%
Iron	40.7%	35.7%	46.3%	47.1%
Zinc	6.7%	10.3%	1800 ppm	832 ppm
Lead	3.0%	4.5%	930 ppm	1080 ppm
Arsenic	1.6%	0.6%	340 ppm	260 ppm
Other	6.6%	13.4%	1.7%	5.8%

EXPLOSION APPARATUS AND TEST METHOD

Test methods to determine the explosion parameters of the dust samples were carried out in 8 and 20 litre explosion chambers. Figure 1 shows a schematic diagram of the equipment layout. The same ignition technique, pressure measurements, recording and timing systems were used for each chamber.

The 8 litre chamber was based on the design developed by the United States Bureau of Mines (Hertzberg, et al., 1979) and a section through the chamber is shown in Figure 2. A 9.4 litre reservoir at a pressure of 500 kPa provided high pressure air to disperse the dust in the chamber. The 20 litre chamber, shown in Figure 3, was similar in design to that developed by the United States Bureau of Mines (Enright, 1984a). This chamber was connected to a 21.3 litre reservoir at 500 kPa pressure.

In each chamber a jet of compressed air was used to disperse dust previously deposited around the base of the chamber. The compressed air passed through a solenoid and non-return valve to the base of the chamber where it was deflected by a cone shaped valve threaded to the base of the chamber. The air dispersion characteristics in the chamber could be altered by changing the height of the cone. The commencement and duration of the air injection were controlled by the solenoid valve. The non-return valve isolated the air reservoir during the explosion. Tests were run at various dust concentrations to determine the cone settings and reservoir pressures which produced the maximum rate of pressure rise during a dust explosion.

The ignition source used in the chambers was nitrocellulose (12.3 per cent N_2) which in turn was ignited by an electric spark. A series of test runs with various mixtures of ore and limestone indicated that reproducible results were obtained with a mass of 0.75 g of nitrocellulose (with a thermal energy of 7590 J) in the 8 and 20 litre chambers. In all tests the nitrocellulose was ignited around 20 milliseconds prior to admission of the dust-dispersing air.

Pressure developed in the explosion chamber was measured by a piezoelectric pressure transducer coupled to a charge amplifier. The signal from the charge amplifier was fed to a storage oscilloscope and a chart recorder. The normal paper speed of the recorder was 250 mm/s and the trace provided a permanent record of the maximum pressure developed and the rate of pressure rise.

The maximum explosive pressure, Pmax, determined from the pressure-time record was given by:

$$P_{max} = P_1 - P_2$$

where P_1 = Total pressure rise
P_2 = Pressure rise due to air injection and combustion of nitrocellulose.

The maximum rate of pressure rise was calculated from the pressure time record as shown in Figure 4.

RESULTS AND DISCUSSION

ORE SAMPLE 1

Tests were carried out in the 8 litre chamber with No. 1 ore sample and ore-limestone mixtures at dust concentrations between 160 and 2500 g/m^3. The pressure developed and rate of pressure rise were calculated from a minimum of three test runs at each dust concentration and these parameters are shown in Figures 5 and 6.

The final pressure in the chamber due to the admission of the dispersing air was 140 kPa and the contained mass of oxygen was sufficient to oxidize 2.17 g of pyrite to magnetite. Assuming that the sulfur in the ore was present as FeS_2, PbS and FeAsS then calculated percentage of pyrite in the ore is 69 per cent. Since the total sulfur content of the minerals in the ore, other than pyrite, is 4.5 per cent their contribution to the combustion process can be neglected as a first approximation. Based on these assumptions the stoichometric mass of dispersed ore in the chamber is 3.1 g (400 g/m^3). Experimental results shown in Figures 5 and 6 indicate that the maximum pressure developed and rate of pressure rise occurred at a dust concentration of around 1200 g/m^3. Bartknecht (1981) observed that for many combustible dusts the optimum explosion effects were observed at concentrations two to three times higher than the stoichometric composition of the dust-air mixture.

Samples of the solid particles remaining in the chamber after an explosion were collected and analyzed. The results presented in Table 2 indicate that a high percentage of the pyrite remained unaltered when ore at a dust concentration of 1540 g/m^3 was exploded.

Table 2 - Analyses of exploded dusts

Sample	100% ore		80% ore: 20% limestone
conc.	640 g/m^3	1540 g/m^3	640 g/m^3
Fe	49.4%	50.1%	35.9%
S	15.6%	25.2%	21.7%
Zn	6.3%	7.1%	5.3%
Pb	2.2%	2.6%	2.0%
As	1.0%	1.1%	1.0%
Ca	-	-	8.4%
Other	25.5%	13.4%	25.7%

Results for various ore-limestone mixtures are shown in Figures 5 and 6 and are similar to those obtained with coal-limestone mixtures (Enright, 1984b). The curves show that the addition of up to 20 per cent limestone did not result in a significant decrease in the maximum pressure developed although higher concentrations of the mixtures were required to obtain the same pressure rise as with ore. A significant decrease in the rate of pressure rise was observed with the addition of small amounts of limestone to the ore. Figure 6 shows the maximum rate of pressure rise decreased from 4500 kPa/s with 10 per cent ore to 3000 kPa/s with 90 per cent ore and 10 per cent limestone. Explosions were observed with 60 per cent ore 40 per cent limestone, however a 50 per cent ore 50 per cent limestone mixture failed to explode with an ignition source of 0.75 g of nitrocellulose.

ORE SAMPLES 2, 3 and 4

Experimental results of tests on the No. 2 ore sample determined in the 8 litre explosion chamber with an ignition source of 0.75 g nitrocellulose are shown in Figure 7. The maximum explosion pressures and rates of pressure rise occurred at a dust concentration around 2000 g/m^3. Tests to evaluate the effect of the addition of limestone to the dust were carried out with various mixtures at a dust concentration of 2000 g/m^3 of contained ore. The results of these tests are summarized in Table 3. Also included in this table are the values obtained with tests on the comparatively pure pyrite samples 3 and 4 at dust concentrations of 2000 g/m^3.

Table 3 - Explosion parameters of samples 2, 3, 4
Tests in 8 litre chamber

Sample	Ore: l-stone ratio	Sample mass g	Nitro-cellulose mass g	Pmax Pa	(dP/dt) max. kPa/s
2	100:0	15.6	0.75	300	2300
2	80:20	19.2	0.75	230	1600
2	70:30	22.3	0.75	160	1000
2	60:40	26.0	0.75	60	900
2	50:50	31.5	0.75	No explosion	
3	100:0	15.6	0.75	560	5700
4	100:0	15.6	0.75	470	4800

The explosion parameters of sample No. 2 determined in the 20 litre chamber with an ignition source of 0.75 g nitrocellulose are shown in Figure 8. A comparison of the results presented in Figures 7 and 8 indicated that the rates of pressure rise were of the same order while higher maximum pressures were observed in the 20 litre chamber. The effect of the addition of limestone to the dust was evaluated at a dust concentration of 2000 g/m^3 of contained ore. No explosions were observed with an ignition source of 0.75 g nitrocellulose and a mixture of 70 per cent ore and 30 per cent limestone.

With an increase in strength of the ignition source to 1.5 g, explosions were observed with a mixture containing 60 per cent ore and 40 per cent limestone. The results of these tests are summarized in Table 4 and indicate that the strength of the ignition source influences the explosion parameters of ore-limestone mixtures with a high percentage of inert material. Bartknecht (1981) found for dusts which were not readily ignited that the explosive data increased with rising energy output of the ignition source.

Table 4 - Explosion parameters of sample 2
Tests in 20 litre chamber

Ore: 1-stone ratio	Sample mass g	Nitro cellulose mass g	Pmax kPa	(dP/dt) max. kPa/s
100:0	40	0.75	460	2100
90:10	44	0.75	420	1070
80:20	50	0.75	340	530
70:30	57	0.75	No explosion	
70:30	57	1.00	360	220
70:30	57	1.50	390	590
60:40	67	1.50	180	400
50:50	80	1.50	No explosion	

EFFECT OF ADDITION OF LIMESTONE

The addition of inert dust inhibits the development of a dust explosion by several different methods (Nagy and Verakis, 1983; Richmond et al., 1975; Cybulski, 1975; etc.). The combustion of the pyrite is retarded as portion of the heat of combustion is transferred to the inert dust. This dust also inhibits the diffusion of oxygen to the burning pyrite particles and restricts the diffusion of gases form the pyrite. In addition the inert particles shield the pyrite from the radiation energy produced by the reaction of the combustion of other burning particles. When limestone is used as an inhibitor the decomposition of calcium carbonate occurs as an endothermic reaction causing the absorption of heat during an explosion. The carbon dioxide produced during the reaction may further inhibit the explosion.

One of the effects of the addition of an inert powder to a dust is to decrease the percentage of combustible material in the dust. In Figures 9 and 10 the explosion parameters are plotted against the total sulfur content of the dusts tested in 8 and 20 litre explosion chambers. Total sulfur content, rather than pyritic content of the dust was selected as it was difficult to estimate to what degree metallic sulfides, other than pyrite, present in an ore contributed to the development of an explosion. The data presented in Figures 9 and 10 is that obtained when dusts with a contained concentration of 3000 g/m^3 of ore were exploded in the chambers. The total dust concentration of the ore-limestone mixtures dispersed in the chambers increased in proportion to the mass of limestone in the mixture.

The results shown in Figure 9 indicate that the initial decrease in explosive pressure with reduction in sulfur content is slight, but as a limiting value of concentration is approached, the rate of decrease in pressure becomes higher. Similar results for various dusts and inert additives were reported by Nagy and Verakis (1983). No explosions were observed in the chambers with dusts containing less than 20 per cent total sulfur and an ignition source of 1.5 g nitrocellulose.

At high sulfur contents the maximum rate of pressure rise decreased almost linearly with an increase in inert material. The relationship between the maximum rate of pressure rise and the per cent sulfur content of the ore was approximately equal to:

$$\frac{dP}{dt} = 175\ [S-20]$$

where S = per cent sulfur content of the ore

$\frac{dP}{dt}$ = maximum rate of pressure rise kP/s

APPLICATION OF LIMESTONE UNDERGROUND

The effective use of limestone dust as an explosion inhibitor requires that the dust be intimately dispersed in the sulfide dust cloud. Data presented in Figure 10 indicates that an ore containing 60 per cent pyrite, i.e., 32 per cent sulfur, would require 60 grams of limestone per

100 grams of ore to reduce the sulfur content to less than 20 per cent and inhibit an explosion. If it is assumed that the roof, walls and floor of an excavation have been washed clean of dust then the problem remains to determine the mass of dust produced during blasting and its distribution in the underground opening during and after the blast. Little data has been published on the mass of dust produced during blasting. Langefors and Kihlstrom (1963) estimated that with a hole diameter of 40 mm, the thickness of the crushed zone was the same order or slightly less than the radius of the hole. Gustafsson (1973) estimated that the diameter of the pulverized section around a 100 mm diameter hole was 150 mm. Beyond this section a further portion of the hole was crushed but not completely pulverized. On the assumption that the thickness of the pulverized zone is 25 mm then the mass of pulverized rock generated per m of charged hole for various hole diameters is as shown in Table 4. During blasting the ore adjacent to the explosive column would be subjected to high temperatures and pressures and chemical changes would occur. However the speed of the explosive reaction and the insulating properties of the rock would limit this reacted zone. If it is assumed that half of the pulverized rock is discharged, unaltered in chemical composition, into the space around the charged hole then the mass of limestone required to inert the 60 per cent pyritic dust would be the amount required to reduce the sulfur content to 20 per cent (see Fig. 10). This mass of limestone per m of changed hole is given in Table 4.

Table 4 - Theoretical calculations on mass of dust produced during blasting and mass of limestone required to reduce the sulfur content to less than 20 per cent

Hole diameter mm	Mass of dust per m of hole kg	Mass of lime stone to inert 50% of dust kg	Column height 1-stone m
100	39	12	0.85
150	55	17	0.53
200	71	21	0.40

Based on the preceding assumption a 150 mm diameter blast hole, 30 m in length, and 15 m charged with explosives would require 255 kg (i.e. 15 x 17) of limestone to inert the dust produced during blasting. The column height of limestone in the hole would be 8 m. This theoretical mass of limestone is appreciably higher then that used in many current mining operations where a 50 kg bag of limestone is dispersed prior to blasting and column height of 0.5 m is used in the deck spacing. In addition the limestone dispersed prior to blasting may not mix with the dust ejected from the blast hole.

Limestone dispersed in the underground openings prior to blasting may not be an effective method of inerting the dust ejected vertically from the blast hole. This ejected dust will be in a highly turbulent state and will initially occupy the space above and around the top of the drill bench. The limestone dust dispersed from a bag will tend to be distributed throughout the excavation and be of minor use in inerting the ejected dust cloud.

In a coal mine the limestone dust is distributed on the roof, ribs and floor of the headings after the coal has been extracted and the mass of limestone transported with the coal is minimal. Limestone dispersed prior to and during blasting in a metalliferous mine will tend to be mixed with the ore.

CONCLUSIONS

Tests in 8 and 20 litre chambers indicated that pyritic dusts with sulfur contents greater than 20 per cent were capable of producing dust explosions. Explosive pressures of 300 kPa and rates of pressure rise of 1600 kPa/s were observed with dusts containing 30 per cent sulfur.

The data available on the mass of dust produced during blasting operations and the disposition of the dust during and after a blast are limited. Theoretical calculations indicate that the mass of limestone dust used in current mining operations may be inadequate to prevent or inhibit sulfide dust explosions.

Consideration must be given to the effects of using large quantities of limestone for dust suppression. Problems may include the formation of calcium oxide when limestone is used in the blast hole and quantities of calcium carbonate in the mined ore may have a detrimental influence in the flotation circuit for sulfide minerals. In addition acid mine water may react with the limestone to precipitate hydroxides. It is therefore important that further studies be made to more fully understand the manner in which the addition of materials react to reduce the explosibility of certain dusts. These studies may indicate that inert dusts other than limestone may be more suitable when large quantities are required in metalliferous mines.

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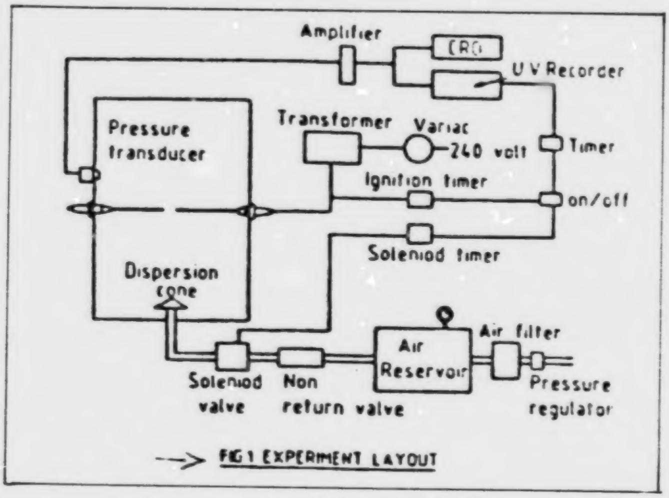
Amplifier
CRO
U V Recorder
Pressure transducer
Transformer
Variac
240 volt
Timer
Ignition timer
on/off
Solenoid timer
Dispersion cone
Air Reservoir
Air filter
Solenoid valve
Non return valve
Pressure regulator
FIG 1 EXPERIMENT LAYOUT

Fig. 1 - Experiment layout

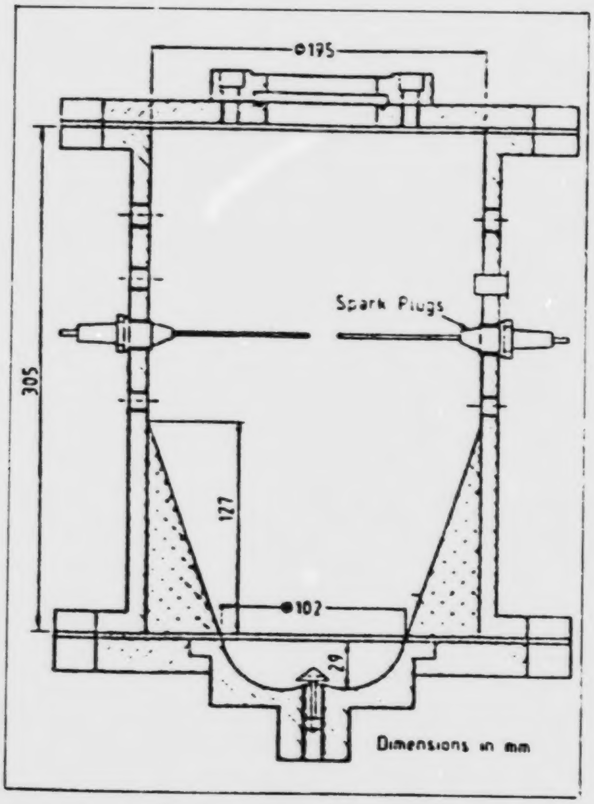
Ø175
Spark Plugs
305
127
Ø102
29
Dimensions in mm

Fig. 2 - 8 litre explosion chamber

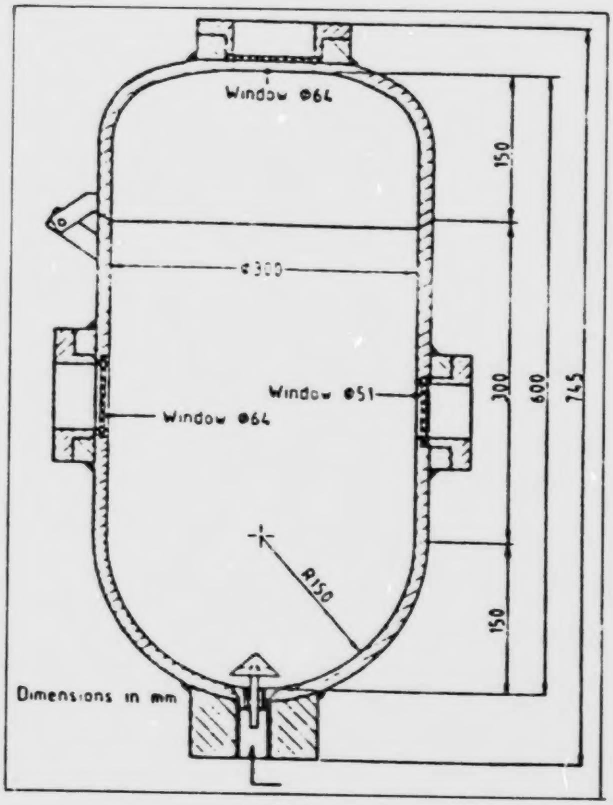
Window Ø64
150
Ø300
Window Ø51
Window Ø64
300
600
745
R150
150
Dimensions in mm

Fig. 3 - 20 litre explosion chamber

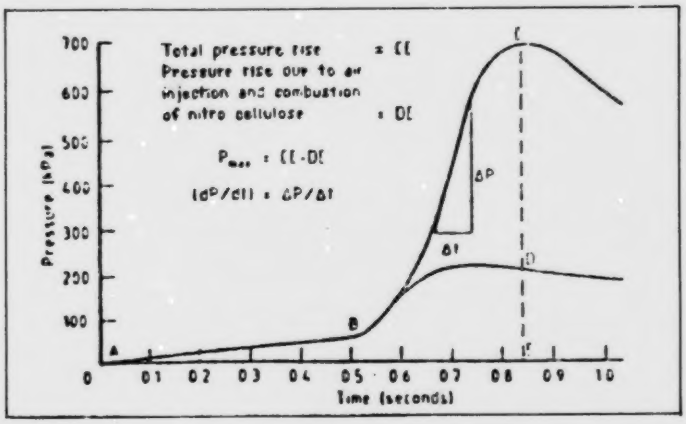

Fig. 4 - Composite pressure-time curves for air injection and combustion of nitro-cellulose (ABD) amd explosion (ABC)

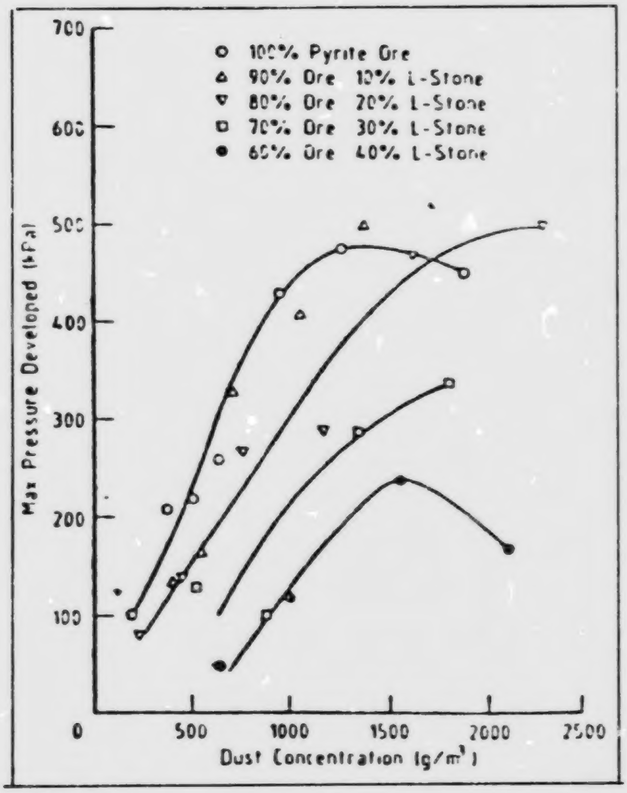

Fig. 5 - P_{max} versus dust concentration with ore=limestone dust mixtures sample no. 1

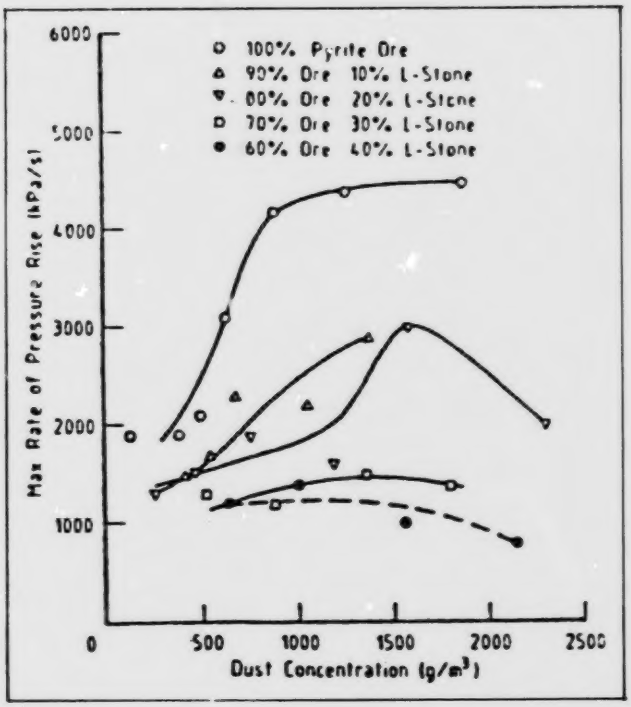

Fig. 6 - $(dP/dt)_{max}$ versus dust concentration with ore-limestone dust mixtures sample (No. 1)

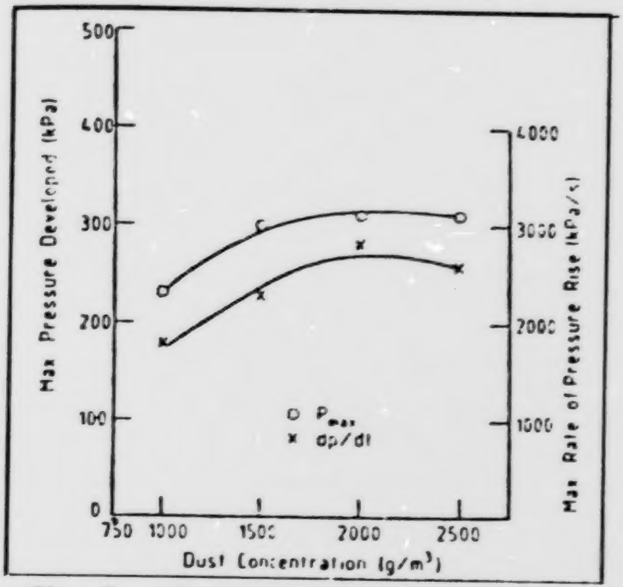

Fig. 7 - Explosion parameters of no. 2 sample in 8L chamber

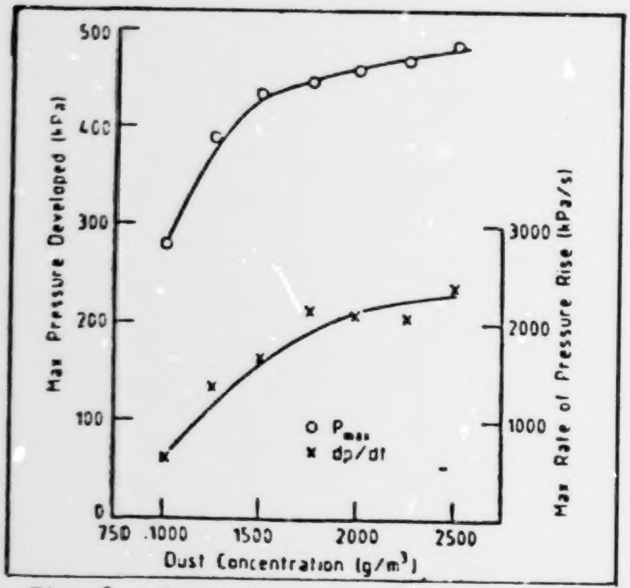

Fig. 8 - Explosion parameters of no. 2 sample in 20L chamber

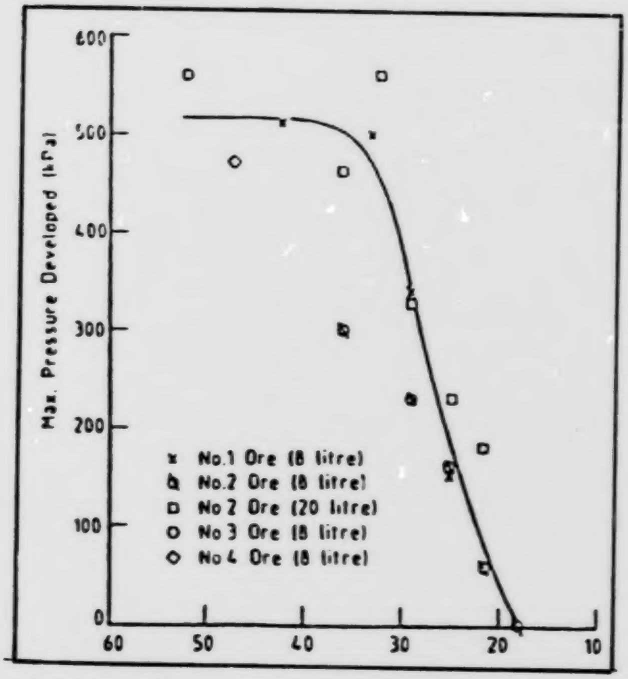

Fig. 9 - P_{max} versus total sulfur content of dust

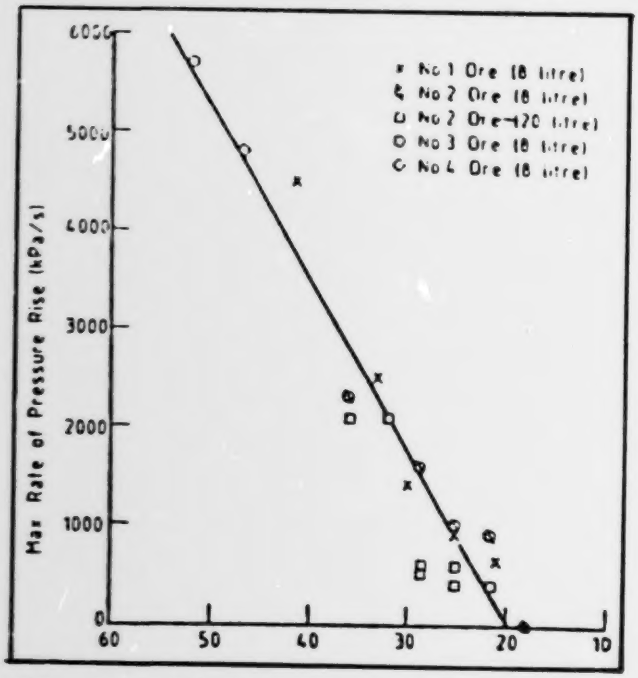

Fig. 10 - $(dP/dt)_{max}$ versus total sulfur content of dust

PART III

Minutes, Conclusions and Actions Recommended

noranda

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Geco Division
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Manitouwadge, Ontario
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Telephone 807 826 3211

November 10, 1986.

Mr. K. Wheeland
Head - Department of Environmental Technology
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Dear Sir:

Thank you for your participation during our recent Sulphide Dust Explosion Conference of October 23 and 24, 1986, held here in Manitouwadge.

As requested, a copy of the recorded data as well as the minutes of the General Dialogue session which concluded the Conference is appended.

A consensus of opinions by those present is included as conclusions and recommendations.

As well it was generally agreed that: -

1. Companies, Institutions, Suppliers, etc. should indicate their willingness to participate in a plan to promote knowledge transfer, control and alleviation, prevention, etc. of Sulphide Dust Explosions.

2. Noranda Minerals Inc., Geco Division will act as co-ordinator of activities at least for an initial two year period.

3. Each Company/Property, Institution, etc. will appoint an individual to co-ordinate local activities, records, data, correspond with other companies, etc. The name of this individual should be forwarded to Geco.

4. Research institutions will contact and liaise with one another.

5. Work by each Mine/Company will be performed as indicated in the conclusions/minutes attached.

6. USBM will be contacted by Geco to act as co-ordinator for U.S. operators. Information to be passed on to Geco.

7. Dr. Enright will act as co-ordinator for Australia, South Africa, and Scandinavia. Institutions and/or operators will be requested to correspond in a similar fashion to Canadian operators.

8. Samples of explosive as well as safe ores will be forwarded to the University of Sydney for analysis.

9. An interim meeting could be held in Toronto during CIM conference in Spring 1987, if necessary. Probable session set for approximately two years hence.

10. Dr. Enright has agreed to continue working with this group to achieve desired objectives.

The main outcome of the Conference as I saw it, was that Canadian as well as world wide concern is shown for the problem. Perhaps by the mining fraternity acting as a group, the problem can be solved.

K.G. Byberg
Chief Mine Engineer

KGB/sw

c.c. J.M. Gordon
P.C. McLeod
F.X. Meagher

GENERAL DIALOGUE - MINUTES

- Expertise is available to research sulphide dust explosions.

- Major point to investigate source of dust, very time consuming but not difficult if a blast investigation is started by controlling different blast types and making measurements of various size fractions.

- Differentiate between breakdown of types of ore to produce dust.

- Investigate why some sulphides ores are more susceptible to sulphide dust explosions than others.

- A central information group (preferably individual) that takes the time to organize the efforts in the problem solving and information gathering.

- Government control of the problem may be a widescale restriction for mining in general and solve the problem by gross regulation.

- The gathering of information by a generalized form to an information data centre may be the answer to the question of how does this and how often does it occur.

- A test facility is necessary to do large scale modeling.

- Geco has been nominated as the primary source for information gathering.

- Commitment from management is required to further follow-up on the solution.

- M.A.P.A.O. has budgeted for research and although limited may be valid to identify some of the research parameters.

- The use of standardized form to record sulphide incidents - Sherritt Gordon to make a standard form by year-end, this will be forwarded to Geco for dispersal.

- When is an incident reported - by SO2 or by damage.
  If no indication of actual sulphide explosion, but high SO2 counts, then a summation of a number of events of this nature is sufficient, or if an SO2 reading is of sufficient level to keep people from working, then this is an occurrence. - Lost Time.

- Is dust composition different from ore composition in a blast?

- Where does dust come from in a blast?

- Each mine can have its own dust chemically analysed for Fe and S before any occurrence, to determine if dust has different composition than the ore. (-90 microns is a good size fraction to collect)

- The dust after an incident should be tested for Fe and S and % magnetite recorded.

- Each operation will determine what is required for its own type of ore - This will be forwarded to K. Wheeland and analysed before sending to Geco towards standardization.

- Sudbury basin does experience some incidents, but very small in nature and therefore not reported. Inco does not have occurrences in files of such and Falconbridge is of the same state. Lower S is definitely involved or that the sulphur oxidizes very slowly and not violent.

- A form for reporting ore to be formed by Noranda Research by year-end and forwarded to Geco.

- Determining the ignition temperature of a particular ore dust is not relative because it is being done in a false atmosphere, and the only way the information will be relative is if the atmosphere in fact created by the exposure is recreated for determination of this ignition point.

- Dupont and CIL will confer to determine the actual atmosphere created by an explosion.

- Determination of dust source and how much is present is an interesting project for U.B.C. however should be performed by an independent operation.

- Noranda Research to discuss dust experimentation with B.M.&S. and Mattagami.

- U.S.B.M. has offered their monitoring system to anyone for testing sulphide dusts for any ore - a collaboration for this sort of work between Canmet and U.S.B.M. can give some real results. But it must be determined what is to be done.

- The physical sampling of dust, etc. from an occurrence would be stored on site if necessary could be tested after a period when some curiosities develop.

- A suggestion that all companies quantify the methods of dispersing limestone dust and type the water injection and forwarding this to Geco, for compilation.

- Meeting again for follow-up to this subject - May '87 suggested in Toronto as an aside to CIM meeting at that time. (Dupont Suite)

- University of Sydney can try to alter dust explosion chambers to be a more efficient or accurate atmosphere for tests and try the use of water sprays in system.

CONCLUSIONS

1. Problems of sulphide dusts are more frequent than previously considered by individual companies. Many companies thought their problems to be almost unique to their ore bodies.

2. Dust explosions are a serious threat to health and safety of mine personnel and efficient mining practices.

3. The total cost of production loss, damage repair and precautionary measures to prevent or inhibit dust explosions is substantially greater than that previously considered by the mining industry.

4. Production loss due to safety measures following an underground blast is significant.

5. Precautionary measures currently in use may be unsuitable or inadequate.

6. Dust explosions can be associated with stope blasting, development or secondary blasting.

The Conference recognized the need to : -

1. Establish a data base so that the magnitude of the problem can be assessed.

2. Request companies to report on the methods used to inhibit or prevent dust explosions and the apparent success or failure of these measures.

3. Request companies to detail the safety measures associated with underground blasting - prior to and after the blast.

4. Promote investigation by the mining companies, explosive manufacturers and institutions into the cause, development and prevention of dust explosions.

ALL MINES - (Initial objectives requiring no additional costs)

1. Compare physical, chemical and mineralogical properties of the mine dust with the ore producing the dust - especially when significant changes occur within the chemical or mineralogical composition of the ore body.

2. Collect, analyse and store dust samples at regular intervals (perhaps samples from U/G Crusher). Such samples may be analysed at a later date.

3. Following a significant dust explosion:
   a) Collect ore samples (min. 10 lbs)
   b) Collect dust samples after the explosion.
   c) Determine path of flame front (and damage).
   d) Determine path of shock wave (and damage).
   e) Determine path of SO2 and other gases.
   f) Report on conditions prior to explosion.

INDIVIDUAL COMPANIES

1. Explosive companies to investigate: -

   a) Temperature and duration of gases from bore holes

   b) Gaseous products and volumes from high explosives.

   c) Physical and chemical properties of stemming ejected from bore holes.

MINING COMPANIES

1. Dispersion patterns of limestone dust.

2. Dispersion pattern of water sprays.

3. Dust produced during mining.
   a) from individual bore holes.
   b) from a development heading.
   c) from a stope blast.

4. Sudbury Basin Relationship to dust explosions.

5. Standard reporting forms.

Actions taken as of April, 1987

(1) Geco has initiated periodic distribution of information on this topic;

(2) Sherritt Gordon has prepared a draft report form for investigating and documenting incidents;

(3) Noranda Research has commenced an evaluation of the explosivity of dusts from several areas of numerous Canadian mines;

(4) USBM and Dupont are evaluating a prospectively lower risk explosive;

(5) CANMET is proceeding with the definition of a contracted out research program. and is developing test facilities;

(6) CANMET and USBM are discussing a *Cooperative Research Agreement*;

(7) Noranda is convening a follow-up meeting of involved parties in its Toronto offices on May 6, 1987.

Appendix 'A'

Agenda and List of Participants

SULPHIDE DUST EXPLOSIONS

MANITOUWADGE, ONTARIO

THURSDAY, OCTOBER 23, 1986 & FRIDAY, OCTOBER 24, 1986

COPPER CAVE CONFERENCE ROOM (DOWNSTAIRS)

AGENDA

Thursday, October 23, 1986

8:30 A.M. - Opening remarks Mr. P.C. McLeod - Vice President Operations - Geco Division
8:45 A.M. - Geco Sulphide Dust Explosion - K. Byberg - Chief Mine Engineer
9:10 A.M. - Sherritt Gordon - Case History - Speaker unconfirmed
9:30 A.M. - Mattabi Case History - J. Wotton - Superintendent Health, Safety & Training
950 10:~~10~~ A.M. - Dr. R.J. Enright - Head Mining Engineering - University of Sydney - Australia
- Coban Mines N.S.W.
- Boleden, Sweden Case Histories

Preambles

Statistics on reported explosions in stope blasts, development headings and secondary blasting.

12 Noon - Lunch

1:00 P.M. Dr. R.J. Enright Text

1) Variables which influence the explosibility of a dust
   a) Chemical compositions.
   b) Particle size and distribution (e.g. does FeS2 produce fines more readily than gangue mineral?)
   c) Dust concentration.
   d) Ignition energy.
   e) Addition of inert materials; limestone, moisture.
   f) Spatial characteristics.

2) Development of dust explosions.
   a) Primary dust explosions.
   b) Secondary dust explosions.

3) Laboratory tests on dust explosibility and their applicability to mining conditions.
   a) Lab tests and parameters derived.
   b) Incorrect conclusions by various researchers.
   c) Details of experimental results on addition of limestone.
   d) Details of experimental results on addition of water.
   e) From laboratory to underground mining.
   f) Techniques available, after an underground explosion, to determine the path and violence of the explosion.
      i) magnetic; ii) microscopic; iii) S.E.M.

4) Proposed theory on the development of sulphide dust explosions.
   a) Stopes.
   b) Development headings.

4:30 P.M. - Discussion

6:30 P.M. - 7:00 P.M. - Cocktails

7:00 P.M. - 8:30 P.M. - Banquet - Guest Speaker Mr. J.M. Gordon
Vice President - Noranda Minerals Inc.

Friday, October 24, 1986 Text (contd.)

8:00 A.M. - Brunswick Case History - B.W. Jamieson - Superintendent Mine Engineering
8:30 A.M. - Dupont Explosives - Speaker unconfirmed
9:00 A.M. - Noranda Research - K.G. Wheeland - Head, Dept. of Environmental Technology
9:30 A.M. - Dr. R.J. Enright

5)* a) Residual dust.
b) Borehole blasting.
c) Collision of rock particles.

6)* Ignition Sources
a) Primacord.
b) Effect of delay intervals.
c) Type of explosives (why do some types of explosives tend to be associated with more frequent dust explosions). Manufacturers may be able to supply answer if given prior notice.

7)* Prevention of Dust Explosions
a) Limestone (how much, when and where placed).
b) Water - washing down, sprays and foggers.

8)* Inhibition of Dust Explosions
a) Passive and triggered barriers.
b) Foggers.

9)* Effects of Dust Explosion
a) Flame front.
b) SO2, and H2S.

10)* Safety
a) Evacuate mine prior to blasting.
b) Men in underground refuge bay.
c) Men underground with S.C.S.R.

12 Noon - Lunch

1:00 P.M. Dr. R.J. Enright

11)* Future
a) Form an association to establish a registrar on all sulphide dust explosions and circulate to members.
b) Indicate future research areas.
c) Support research, etc.

2:00 P.M. - Discussion

3:00 P.M. - Closing Remarks

* Text of these papers to follow late

SULPHIDE DUST EXPLOSION CONFERENCE

Manitouwadge, Ont.
October 29-31,1986

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Geco personnel in attendance

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Mr. B. Friesen	Head, Geology Department
Mr. R. Girard	Safety Department
Mr. K. MacNeill	Senior Blasthole Technician
Mr. G. Marjerrison	Shift Supervisor
Mr. P. McLeod	Vice President, Operations
Mr. F. Meagher	Mine Superintendent
Mr. D. Sands	Senior Planning Engineer
Mr. A. Turner	Safety Department
Mr. J. Ward	Health and Safety Representative
Mr. D. Beattie	Planning Engineer

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Appendix ‘B’

Summary of the Workshop

SULPHIDE DUST EXPLOSION CONFERENCE
PROCEEDINGS

OCTOBER 23, 1986

OPENING REMARKS; P.C. MCLEOD, VICE-PRESIDENT-OPERATIONS -NORANDA INC.

The sulphide dust explosion which occurred at Geco in October 1985 led to this conference being organized.

Geco operated for 31 years with no mishaps until that day on October 8.

Dr. Enright was consulted on the Geco incident and helped a great deal with analysing the circumstances surrounding it.

When organizing the conference, Dr. Enright was approached and was planning a trip to North America. (The dates were set accordingly).

This problem is significant in many mines and hopefully a solution can be found.

1. M SAPKO - SUPERVISORY CHEMICAL ENGINEER, FIRE AND EXPLOSION GROUP, UNITED STATES BUREAU OF MINES

FILM: BRUCETON MINE EXPERIMENTAL DUST EXPLOSION - APRIL 1, 1969

Camera located outside portal showing fire ball exiting mine with tremendous force.

The result of this experiment was more destructive than anticipated.

BACKGROUND: "CAUSES AND PREVENTION OF DUST EXPLOSIONS AND FIRES"

18,000 coal miners have been killed by dust explosions

EXPRIMENTAL SET-UP: 300 lbs. of Pittsburgh coal dust placed on shelves along drift entrance, primacord was used to disperse dust and then dynamite used to ignite dust.

74 micron coal dust with 6.5% methane.

RESULT:
Very violent - Broke all instruments, tore out concrete bulkheads, ripped out timber which blocked portal, windows were broken within 7 miles and could be heard up to 30 miles away.

Now only experiment with small explosions which create 1 PSI at portal, no temperature inversions can be present, so the weather must be monitored closely before firing a dust explosion.

SULPHIDE EXPLOSIONS:
Obtained 500 lbs. from Brunswick Mining and Smelting at 1% Cu, 10.9% Zn, 37% S

Explosions have been simulated in a test chamber, 5,000 joules is upper limit, 550 gm/m3 required to sustain propagation (at 30% S, 670 gm/m3)

PLOT: PRESSURE VS. DUST CONCENTRATION
Graph shows coal dust more explosive than oil shales at 44-50 gpt and 35 gpt with sulphides below this level.

MINE TESTING; using remaining dust, loaded opening with dust, dispersed dust and then initiated with 1/2 lb. Anfo,transducers, monitors, etc. used to measure pressure and propagation speed. (700 to 800 mg/l to propagate sulphide explosion).

OIL SHALE RESEARCH: 100's of tests, varying particle size, etc. in Colorado, to develop characteristics.

COLONY MINE, EXXON: Data gathering
4.25 in. diameter blastholes, 4200 tons per blast, room and pillar full face blasting, large openings, presplit at walls, B-cut, 30 ft. holes, Anfo explosive, 1 lb. boosters, no stemming, nonel with E-cord, No. 8 caps, 600 ms., high dust concentrations.

Instrumentation installed in opening, high speed film recording of blast.

Pressures, wind velocities, etc. measured (wind forces may be important to the spreading of dust for full scale propagation).

PLOT: FLOOR DUST LOADING/NOMINAL DUST CONCENTRATION VS. DISTANCE FROM FACE
to date no indication concentrations are significant for full scale propagation.

BACK CALCULATE: 1 PSI. approximately 55 ft/sec. wind velocity
Conclusions:

1. Sulphide dust appears to be a rather difficult material to ignite and is much less violent than coal dust.

2. Influence of methane on shale dust explosions appear to be significant; variance from 18-60 cu.ft./ton of methane.

3. The smaller the dust particles are, the less material is required to create the hazard and is more likely to ignite.

2.K. BYBERG - CHIEF ENGINEER, NORANDA INC. -GECO DIVISION

GECO SULPHIDE EXPLOSION INCIDENT - OCTOBER 8, 1985 AT 11:55 P.M.

BACKGROUND

The Geco orebody is a Cu, Zn, Ag lenticular shaped, steeply dipping deposit, plunging 35 degrees to the East for about 5500 ft.

The reserves are listed at 55 million tons with 42 million tons mined to date. The present mining rate is 4100 tons per day.

The mine presently operates from 2 shafts: No. 1 Shaft in the west end of the deposit to the 2450 level, and No. 4 Shaft in the east end of the deposit to the 4050 level. Both are friction (Koepe) hoists.

The present mining method is blasthole under waste fill. Typical stope dimensions are 70 ft. along strike, 80 ft. thick and 400 ft. high. Pillars are 120 ft. along strike, all other dimensions the same. A slot is created in the center of the stope with a 20 percent void being removed before blasting the remainder of the ore.

Production is carried out with 125 H.P. slushers in scrams at the bottom of each lift, pulling the ore down under the quarry waste rock introduced from the top. The ore/waste interface is pulled using a draw control program designed for each stope, dependent on shape, size, etc. and maintained for the stope life by computer. Cement mill tailings or straight hydraulic fill is used to consolidate the quarry rock for stability once the ore is recovered.

On October 8, 1985 11:55 P.M. the No. 23 void blast on 24-46 sub in the 26-46 pillar was blasted from surface. All personnel were removed from the mine,except for a 3 man drift crew on the 3850 level, 1400 ft. below the void blast. A drop raise was being fired from the 2350 directly above the void blast. This was not a normal procedure for Geco blasting.

10,000 to 20,00 CFM is vented through workings from 2450 level with 10,000 to 20,000 CFM passing on each level. Stope sulphur content is 28.3% and is the largest stope in Geco history at 925,000 tons. The two stopes on either side are mined and filled with cemented tailings. The grades of the two previously mined stopes are similar to 26-46, but there was no occurrences in either stope of SULPHIDE explosions.

The sulphide explosion momentarily reversed the ventilation. Pieces of destroyed vent door were found a good distance from its installation point, counter to the flow of ventilation.

The ventilation input is 500,000 CFM total through the No. 1 Shaft vent raise (200,000 CFM)and No. 4 Shaft itself (300,000 CFM). No. 1 Shaft acts as an upcast airway and there is a vent pipe in No. 4 Shaft which exhausts 60,000 CFM from the lower levels.

The S02 was forced down the main ore pass from 2650 to the 3850 level crusher, through an unknown amount of muck above the head block and into the drift. 10,000 CFM usually flows in drift and vented through shaft vent pipe. In this case the air was forced to drift fan, where it was picked up and carried to the drift crew. There was 1 fatality and 2 serious injuries as a result.

Fresh dust was scattered around crusher floor, etc. that indicated there was a great deal of force behind the shock wave, or pressure front.

CONCLUSION:
Believe that the void blasting was causing a great deal of dust and the drop raise was firing up to 500 ms. after void blast was completed.

3. LUCIEN NEL - VENTILATION ENGINEER, SHERRIT GORDON MINES LTD. RUTTAN OPERATION

Precautionary measures have been developed to prevent and minimize rehabilitation costs,lost production, injuries, etc. but are still not enough.

Ruttan started as an open pit, but have been underground since 1979 mining 6,000 tons/day.

The Cu/Zn deposit is made up of lenses, the east and west lenses being the main mining areas.

The east lens has been the main point of consideration for sulphide ignitions, but a few incidences in other lenses has also occurred.

There is a great amount of pyrite lenses in the ore sometimes reaching as high as 100% in the ore horizon of the east lens. Sulphur content ranges from 43% to 53% for the pyrites throughout the mine.The east lens pyrite is recrystalized with larger grain size and is fragmented very easily, creating fine dust.

MINING: use 4.5 in. and 6.5 in. diameter blastholes for stoping. A raiseborer is used to cut the slot raise after which holes are blasted to form void. All mucking is by scooptram from the stope bottom. The stope is always open and is not a container but an open system.

Explosives are all of the non-aluminized variety. Agricultural lime is used to stem all holes and all blasting is conducted at shift change when the mine is clear of personnel.

VENTILATION: general flow is from east to west and footwall to hangingwall. Exhaust is on the hangingwall with intakes on the footwall. The occurrence of a sulphide blast has a chance to clear from the main workings.

In the lower mine, development not completed and these paths have not been established. All ventilation is through auxiliary systems. When a sulphide blast occurs the auxiliary systems are damaged and SO_2 pockets are produced. This has an effect on production and causes prolonged delays.

BLASTING: use a wooden plug in the bottom, 3 ft. of lime, nilite charge column and 10 ft. of lime for the collar. Also suspend 10-15 lb. bag of lime in stope.

CASE HISTORY: 26J STOPE - MOST RECENT AND MOST VIOLENT

July 22, 1986 at 12:00 Midnight.
First indication - cage returned from post blast run in shaft with a 50 ft. length of 42 in. vent duct stuck on it. This was blown from the stope to the 730 shaft station. Other tubing was found in shaft and at the station.

Two return air fans were blown off mountings and carried 22 ft. from installation location.

Five shift delay was experienced while return air system was re-established for the lower mine. No injuries were encountered.

The deeper mining progresses, the more frequent are the occurrences.

Dr. Hall, U.B.C., has been contracted to do research and establish a control program for Ruttan. (7 steps).

EFFECTS OF SULPHIDE EXPLOSIONS

1. Cost - material damage

2. Safety

3. Lost time

LINE OF DEFENSE

Try to limit time delay to 200 ms, this may not allow the situation to optimize for a sulphide explosion.

Non-aluminum explosives are used to keep initiation temperatures to a minimum.

A fogger is lowered in all stopes to wet area 8 to 16 hours before blast time (lime is kept dry in plastic bags).

A new approach to each blast is being taken with an analytical attempt at predicting potential sulphide explosion situations. The result is assessed, if there is a blast, and a determination of these blast parameters is used to try and predict a potential blast given the historical data, etc.

4. J. WOTTON - SUPERINTENDENT HEALTH, SAFETY AND TRAINING MATTABI MINES LTD.

In the last 10-12 years there has been a large number of secondary blasts.

Will only discuss most recent 10 incidents:

1. October 16, 1980 - Development drift round, 3 men gassed, lime stemming was used.
2. 1981 - Drift round, High SO2 content after blast, no other indications.
3. 1981 - Sand blasting oversize, 50 lb. Amex, S level at 35%, damaged tubing and red dust found.
4. September 1981 - Drop raise, 2nd blast, no precautions taken previous to blasting, low grade area was blasted with no problems beforehand.
5. October 1982 - Stope blast, 1500 tons blasted, lime and sprays were used, only vent duct damaged, stope drawpoints were empty, was lots of air ventilating stope (the recommendation made was to keep drawpoints full).
6. October 1982 - Pole blast in drawpoint, 12 sticks of powder, surface initiation, no precautions taken prior to blasting, bulkheads damaged, air and water lines displaced.
7. April 1985 - Lyon Lake - Subdrift round, tape fuse initiated, one man injured from concussion, red dust.
8. October 1985 - Suspected, but no indications.
9. 1986 - Primary stope blasts, all precautions taken.
10. 1986 - Primary stope blasts, all precautions taken.

Mattabi incidences cover a wide range of circumstances, mostly during development with a variety of explosives, timing, etc.

Believe a standardized form should be used to record these incidents: MAPAO may be a good source for this.

Information should be gathered with materials of all size ranges; fist size down.

Wetting is most critical, with lime bags as well.

Limestone stemming and water stemming have been tried in loaded holes.

Procedure for drift rounds - wash thoroughly, stem with calcium Anfo and hang lime bags, which are initiated with first shot.

DISCREPANCIES FROM OTHER PROPERTIES

No containment chamber in some instances and no secondary explosions to set off the dust.

RESULT:

Not enough information on actual initiation parameters to predict explosions.

There has been a link between the sulphur content and dust explosions above 29% S, but many mines have greater than 29% S and have no problem.

DR. R.J. ENRIGHT - HEAD, MINING ENGINEERING - UNIVERSITY OF SYDNEY

Sulphide explosions have been hidden for the most part, until now.

TWO CASE HISTORIES INVOLVING DUST EXPLOSIONS:

1. ELURA MINE, NEW SOUTH WALES

No injuries recorded.

OREBORY: Elliptical shaped; pyrite arsenopyrite, pyrrhotite, sphalerite and galena are main minerals. Three main zones make up orebody - pyrite, pyrrhotite and siliceous.

ORE ANALYSIS:

S	30-37%
Fe	24-30%
Zn	9-13%
Pb	5-9%
Silica	0-23%

November 30, 1983: First recorded occurrence
(Have had one/Yr. since '84 and '85)

Damage: 12 ton L.H.D. and compressor destroyed.

October 1985: Blasted 4 holes - 300 kg watergel and 2150 kg of Anfo in 200 mm holes of various length 15 m to 43 m. Limestone stemming was used in the collars of holes - 400 mm to 4.5 m other stemming.

Damage: not extensive, but a 4 hour delay to the mine was experienced. Water sprays were being used in the blast areas.

2. LANGSELE MINE, SWEDEN - MAY 23, 1969

2 miners killed, extensive damage to 3 mining levels.

OREBODY - complex pyrite ore, mine pyrite for smelter feed.

ORE ANALYSIS :

Cu	0.85%
Zn	3.84%
S	38.7%

At time of accident sub-level stoping was being used, has since been converted to cut-and-fill. On May 13, 1969, a sub-level blast was loaded, 45 mm holes loaded with Anfo and dynamite primers; most of the holes misfired.

On May 14, the misfired holes were rewired and it was fired again; half of the holes again misfire.

On May 23, the misfired holes, containing 800 kg of Anfo, were checked and rewired for firing. 2 shot-firers were underground to detonate the blast and then travel to another level to detonate a raise blast. The mine was evacuated of all other miners. Detonate stope blast on 210 level and then take cage to 260 to detonate raise.

The first blast was fired and shortly after the dust explosion with such force it injured the hoistman when the pressure came up the shaft. The foreman put on rescue gear and climbed to the 210 level where the two shot-firers were found lying in the cage. There were dead when belled to surface - chest damage: not knownif SO_2,or physical.

Mine was down for two weeks to repair damage.

Since that time only small secondary blasts are fired from underground, all other blasts are fired centrally and the mine is evacuated.

SULPHIDE DUST EXPLOSION STATISTICS

Very poor statistics are kept on occurrences.

There have been 10 deaths recorded - 7 by SO_2
14 injuries recorded- 13 by SO_2

The occurrences are as common in stope blasting as in development blasting.

Most injury statistics are from inhalation not from actual blasting damage.

THREE STAGES ASSOCIATED WITH DUST EXPLOSION

1. Flame front - 1000° C
2. Rapidly moving flame front 20-300 m/sec.
3. Pressure rise involved - damaging to equipment, etc.

Tests at 100 kpa (14.5 psi) damaged 4 in. concrete
Damage to personnel at 1.5 psi.
Products of combustion - SO_2, Co, H_2S (combined with a lack of oxygen).

Coal mines have done much work, which is related!
However, uses of some technology from coal is not always to be applied indiscriminantly, the solutions are not transferable based on orders of magnitude.

COAL MINES:

Early 1800's - Introduction of gunpowder, increase in explosions.

Methane was learned to cause explosions, therefore the introduction of fire-starters who ignite the methane pockets in working areas.

Safety lamps were introduced in 1815.
1844, Faraday recognized coal dust was explosive, this was not accepted, but was proven 1909.

Limestone dust (stone dust) was used to reduce explosions; was cheap to mine on surface, white for good reflectivity and as a marker to determine areas dusted and is inert to health.

Lately, many situations have been a result of the coal dust explosion, not CH_4, 1970's

In new South Wales, mining for 50 years previous resulted in no disasters, in 1979, 14 people were killed, therefore just because no occurrences are recorded doesn't mean it can't happen.

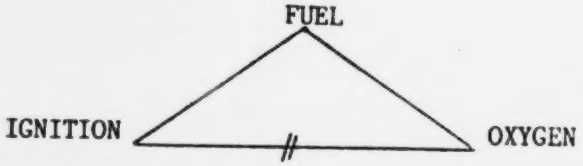
Grain dust has also been a long running disaster problem, but wasn't recognized until 1977.

MECHANICS - FACTORS INVOLVED IN COAL DUST EXPLOSIONS

Very rapid combustion.
Difference between fire and explosion (both require the same constituents) - rate at which energy is released.
Anything that will burn, can explode.

DUST EXPLOSIONS REQUIRE :

1. Dust must be finely divided and in suspension (not explosive if not in suspension)
2. Require oxidizing agent.
3. Require source of ignition.
4. Require some means of confinement.



Must break the chain in any link to eliminate the problem.
Breaking the chain in as many links as possible adds to certainty.

Venting in a mine usually solves the possibility of a problem, but in a mine is not easy.

FACTORS WHICH INFLUENCE DEVELOPMENT AND SEVERITY OF EXPLOSIONS.

1. FUEL

Chemical composition, % pyrite and % other S (Galena, sphalerite, Chalcopyrite, etc. also explosive) therefore all S content should be considered.

Adding inert material - is dust same chemical composition as rock.

The red dust so many use as a indicator is in fact the last chemical reaction in chain - S can be present without going to hematite.

Magnetite is present as first reaction product.

In experimental combustion chamber:

Test to produce a pressure vs time graph

Rate $\frac{DP}{DT}$ gives an indication of magnitude

Curves for: max. pressure vs. dust concentration
Pressure rise - max vs. dust concentration
(Adding rockdust) Max pressure developed vs. dust concentration
(Experimentally can get an explosion with any addition of inert material) therefore, limestone not solving the problem when used to prevent explosions.

PARTICLE SIZE Smaller particles more ignitable, the increased surface area is critical.

DEFINITION OF DUST (COAL)
Less than 75 micron to 90 micron (Larger can still be explosive)

The surface area can be large if a large number of voids is present on particles.

Particle size distribution - small particles easily ignited which can ignite larger particles.

Settling velocity less for smaller particles, but the density of the dust is critical for this.

VARIABLES COME INTO PLAY:

Lower and upper explosive limit
Methane CH_4 - 5 to 15%
Petroleum ~8 to 50%

but, gas occupies entire volume.

Dust doesn't occupy entire volume, difficult to make limits, therefore no real upper limit.

Dust can be residual or produced:
Residual dust occupies walls, back and floor, is considered explosive if can run finger through it, 500 g/m3 - therefore, a very small amount is all that is required.

2. IGNITION

Minimum ignition temperature and energy

-Coal requires very little to ignite gas/vapor mixture
-Hard rock however, has large volumes of material in question, but large blasts have some unexploded material which continues to burn, etc.

3. OXYGEN

*Not practical in work areas.

SHAPE AND SIZE OF CONFINING SPACE

The size of vessel and ventilation required for a particular shape of vessel is important.

The explosion direction is unpredictable.

PRIMARY AND SECONDARY DUST EXPLOSIONS

(Primary refers to first dust explosion - not explosives shot)

Primary is usually of a minor nature, but causes dust to be disturbed and the flame ignites the dust now dispersed.

Shock front is faster 374 m/sec while flame front starts slow 50 m/sec.

As flame front speeds up, the flame front/shock front will meet, therefore must distribute inert material, etc. at proper intervals to stop initiation of secondary blast.

In blasthole stoping, impossible to rock dust, but washing all drifts to clear dust and make it inert is possible.

Usually hardrock is a difference mechanism than coal. Initiation of explosives after initial dust cloud is formed may be potential problem.

LABORATORY TESTING EQUIPMENT

Explosion chambers to test concentration of dust initiations and measure pressures, etc:

1. Depends on size and shape of vessel
2. Depends on dust dispersion system
3. Depends on ignitiation system, location and temperature etc.

Results are dependent on chamber and different results will be obtained for different chambers.

Measure max. pressure and rate of pressure rise
Rate of pressure rise is a function of ignition energy
Run a number of tests at various concentrations of inert material additions: ie. rock dust, red sand, salt, etc.
Plot graphs of pressure rise vs. non combustiles in mixtures.
Results prove that any inert material is substantial and that limestone is not the only material available.

Limestone is used to:
1. Absorb energy
2. Shield heat
3. Interfere with combustion
4. Increase minimum initiation energy

ANALYSIS OF EXPLODED DUSTS:

Highly significant reduction in S for less originally dense concentrations, but not an indicator where high densities are common.

Ignition energy an important factor for seeking a non-explosive mixture.

Maximum pressure is developed from pure pyrite at 52% S down to 30% S, with no explosions at less than 20% S, but from 26% S to 30% S, the curve is very steep and is very susceptible to changes in the (environment) parameters and violent explosions can result.

The mixture in the field is not an intimate mixture in the dust cloud - 60 g stonedust to 100 g ore at 32% S. Important to learn how much dust is produced and where it is produced, if all the workings are clean. Using the assumption that a 25 mm pulverized area around a blasthole is produced when blasting, a graph of the dust produced vs. inert material required to inert 50% of dust is made,to estimate the inert material per m of blasthole fired.

The use of limestone as stemming is almost equal to the column length of explosive, therefore making it very difficult to justify the logistics of adding limestone; fragmentation, burden, etc.

WATER ADDITIONS:

Maximum pressures dropped off as water content was increased.

Free water: absorbs heat from blame front
: has a heat of vaporisation
: can't act as a shield

Acts to bind particles and lowers pressures as a result of the larger particle size.

Water inclusions can cause the formation of H2S.

5. F. HERMANN - SENIOR PROJECT ENGINEER, BRUNSWICK MINING AND SMELTING

Sulphide dust explosions have not been a major problem.

Majority of occurrences are on 1000 m level over the past 3 years.

Started in development phase and was most common when multiple faces were in close proximity, usually damaging ventilation ducting.

Pyrrhotite seems to be 8 to 9% in this area and dust buildup is a problem.

Dust explosions occur in other areas, but only in high pyrrhotite.

Water is used to wash all headings 100 ft. from face.

Water stemming is used in all holes, bags of lime are hung 20 ft. from face and water sprays are left on 20 ft. from face, behind lime.

Precautions are not adhered to consistently now, but only in areas of high pyrrhotite, the proximity of multiple faces is also no longer a problem.

Minimum sulphide explosions in cut and fill due to the cyclical operation; washing muck pile for mucking, bolting, etc., therefore water is present.

Transition to longhole on 1000 m, but before cut and fill there was longhole.

Blasthole stope left for 5 years, partially blasted

The stope was not washed before blasting, when first blastholes were fired a sulphide explosion resulted. Bulkheads were destroyed, skip guides displaced in shaft, equipment moved, SO2 gas expulsion, etc.

After this a procedure was required proceeding blasts.

1. Prewashing all areas in a blast.
2. Hanging lime in accesses
3. Hanging lime in stopes
4. Water sprays in accesses and stope

QUESTIONS BEING ASKED BY GROUP:

Q. Relationship with pyrrhotite and sulphide explosions, which is also an oxidation problem?
A. There may be a relationship.

Q. How much and where is lime?
A. Stope is surrounded by lime during blasting; hanging in stope, behind blast in drifts and on holes to be blasted - totals about 500 lbs. or more.

Q. Any aluminum blasting agents?
A. None.

6. K. CASEY - NATIONAL MARKETING MANAGER, DUPONT CANADA INC.

DUST EXPLOSIONS

Main Factors - Uses explosive properties simulated in the computer model 'BLASPA'

Simulations couple the thermodynamics of explosives with rock properties and configuration.

T/D - temperature of detonation - inside explosive up to 5000 °K and only for short duration - 5 x 10-6 sec.

T/X - temperature of explosion - longer duration.

Detonation temperature is at initiation and temperature of explosion is reached during movement of flame wave front.

Neither temperature seems to be a good criterion for the estimate of predicting a dust explosion.

MAIN MECHANISM OF A BLAST

First: strong compressive wave which travel from explosive.

Second: reflective tension waves cause breakage (rock is usually weak in tension).

The first stage is where dust in the hole is generated and rock is intact.

The tension wave causes primary fragmentation, secondary fragmentation is caused by gas penetration moving toward free face to vent,cratering has only one face for venting, while slashing has more than one.

T/E - Temperature of gases, is lower than T/X

Exhaust temperature T/E at gas/dust/rock interface lasts until dissipated (not a short time)

$T/E < T/X < T/D$

In a particular blast - factors affecting T/E

1. Rock type
2. Explosive type
3. Charge distribution
4. Stemming material
5. Collar, spacing, hole length
6. Explosive/rock coupling

T/E can vary depending on above - not explosive temperature.

This temperature of gases should be considered important in dust explosions - not a factor of explosive alone, but the use of the explosive - quality vs. potential.

MODEL 'BLASPA'

1. Elastic properties of the rock is required for simulation: Young's modulus, poisson's ratio, etc.

2. Blasts geometry is needed for simulation.

3. Explosive type

Simulations can be conducted for varying stemming.

RESULT: INCREASE STEMMING - reduces T/E as much as 800° K to a specific stemming length and then flattens.

CHARGE LENGTH - reduces T/E, but not significantly.

EXPLOSIVE TYPE- fixed charge length, varying stemming from 0 to 41 lbs.
- adding aluminum or other similar agents raises T/E

Therefore stemming is critical - Anfo unstemmed has a high T/E and is larger than some lightly aluminized water gels.

GENERAL STUDY QUESTION:

What is ignition temperature of sulphide dust and how does it tie in to T/E

At Sherrit Gordon, Ruttan an estimate of 1700° K was used; based on tests explosions at 1900° K and no explosions at 1500° K, average.

NOTE: All simulations are for crater blasting, but can also simulate slashing.

Practice requires a safe blast, but demands acceptable blasting results; fragmentation, etc., therefore some limitations on minimum product strengths.

SUMMARY: Two most important factors appear to be the stemming and the explosive type to control the exhaust gas temperature, which in fact is a means of controlling dust explosions.

Stemming: primary function control gases, if in fact acts as a heat sink.

QUESTIONS BEING ASKED BY GROUP:

Q. Why was salt used as a additive to Anfo?
A. It was used to act as a heat sink, and is a factor of 4 better than lime; ie 4:1.

Q. What would one predict the T/E to be for slashing?
A. The T/E would be higher for slashing.

7. K. WHEELAND - HEAD, DEPARTMENT OF ENVIRONMENTAL TECHNOLOGY, NORANDA RESEARCH CENTER

1979 - Two operations indicated problems of dust explosions.

Took samples from various Noranda properties to test in explosion apparatus.

Tested diluents of various types - no difference in results, all diluents were sulphur free.

Ignition temperature of sulphide dusts was determined at various % S.

A questionnaire was sent out to determine what type of precautionary measures are being used to eliminate the likelihood of sulphide dust explosions.

Water and lime were major use items.
Sprays received mixed results.
Changing explosives was stated
Controlling timing was stated.

FACTORS CONTRIBUTING:

%S, friability, detonation delays, dustiness, explosive type, mining method, geometry of workings.

PRACTICES USED TO CONTROL:

Direction and quality of ventilation, clear men from mine, equipment removed from area, air quality check before re-entry.

SUMMARY:

1. Important to document all incidences in a consistent manner and to distribute these results to help others.

2. Maybe Inco or Falconbridge can help with the answer to some of the questions.

DR. R.J. ENRIGHT

Correlating lab results with field results

- seem to have correlation in oil shales.

If a sulphide explosion occurs - where does it travel?

Help to determine point of initiation and direction of flame front.
Find evidence of SO2 chemical reactions and pyrite particles along path of travel.
1st product is magnetite, can determine with a simple magnet in drift.
2nd product is hematite, very difficult to determine, can be red, brown, black, etc.
Chemical analysis not always confirmative
Microscope will allow visual inspection of particles. During reaction of S the particles are turned to spheres with well formed triangular shapes on skin and a hollow interior. Standard geology department microscope is sufficient to analyze particles.

Are there adverse affects from using lime in stopes as an inert substance - CaCO3
Will it affect the mill in large quantities?

In most cases quantities specified are not enough to influence operation.

A dust explosion during firing:

Can't happen inside mass of broken material, too much inert rock around dust.

The movement of a rock mass is in fact finite with a blast face velocity and a gravity velocity eg./ 4.5 in. diameter hole, 100 ft. long.
Burden 7', using Anfo to blast
Calculate V face = 60 ft./sec., g= 32 ft/ sec 2
9 ft. stemming.
Rock mass moves out 60 ft. in 1000 ms and dropped 16 ft.
Rock mass will move 750 ms. before stemming is completely uncovered, therefore 750 ms before a source of ignition is exposed (discounting exhaust gases, etc.)
Indications are that the mass is moving down when secondary sulphide explosions occur - therefore flame front is moving out the top of stope, since this is only path available.

Calculations for any type of blast profile can be completed, but drift blasting is more difficult.

Water sprays in stopes during blasting are questionable as to whether they are sufficient to inert the system, since the explosions are very violent and only a fine spray is usually left on, creating only a very small amount of water in stope.

Limestone in holes may not be as effective since pressures on the stemming during blasting results in compaction effects on the column which may create larger solids which would negate the powder effects.

Brunswick Mining has experimented with distribution of limestone in drifts around the blast and dispersion with explosives.

U.S.B.M. has experimented with water, and even heated water (to steam), to inert the dust. Calculations show that only 1/60th of the water required is necessary when turned to steam.

A continuing question is whether drawpoints should be left full or empty.

Due to the toxicology of SO2, should blasting be done with an oncoming shift or should a period be allowed before entering the mine. Monitoring may also be done prior to entering the mine. The time allowed should be adequate for venting of SO2.

It is important that workers be evacuated when blasting if there is any chance of a dust explosion.

Maybe properties experiencing dust explosions could monitor return air systems to determine what changes, if any, in SO2 content are detected after major blasts.

Geco is in the process of implementing a computer monitored remote control fan system, aimed at controlling all vent fans from a central computer panel. This will record service interruptions and also provide the ability to turn fans on and off. The ultimate system will allow the monitoring of control substances in mine air. Present monitoring systems for SO2 are unreliable.

Installing a monitoring system in a large mine would be very costly to adequately cover all mine workings.

After the Geco incident, no indications of SO2 were in working area in a short period of time, therefore proving a large mine can vent itself very rapidly and leave little evidence of the magnitude of the situation.

Recorded by: Douglas A. Sands

Annexe "B"
Résumé de l'atelier

COMPTES RENDUS DE LA CONFÉRENCE SUR LES COUPS DE POUSSIÈRES SULFURÉES

23 OCTOBRE 1986

MOT D'OUVERTURE; P.C. MCLEOD, VICE-PRÉSIDENT, EXPLOITATION, NORANDA INC.

Le coup de poussières sulfurées qui s'est produit à la Geco en octobre 1985 nous a incités à organiser cette conférence.
La mine Geco a été exploitée pendant 31 ans sans aucun incident jusqu'à ce fatidique 8 octobre.
On a consulté M. Enright qui nous a considérablement aidés à analyser les circonstances entourant cet événement.
C'est au moment d'organiser cette conférence qu'on a communiqué avec M. Enright qui prévoyait déjà faire un voyage en Amérique du Nord. On s'est donc arrangé pour faire coincider la date de la conférence et celle de son voyage.
Le problème des coups de poussières est important dans un grand nombre de mines et nous espérons qu'une solution pourra être trouvée.

1. M. SAPKO, INGÉNIEUR CHIMISTE SUPERVISEUR, FIRE AND EXPLOSION GROUP, UNITED STATES BUREAU OF MINES

FILM : COUP DE POUSSIÈRES EXPÉRIMENTAL DANS LA MINE BRUCETON, 1^er^ AVRIL 1969

La caméra installée à l'entrée extérieure de la galerie montre une boule de feu sortant de la mine avec une violence extraordinaire.

Le résultat de cette expérience a été plus destructif que prévu.

HISTORIQUE : "CAUSES ET PRÉVENTION DES COUPS DE POUSSIÈRES ET DES INCENDIES"

Dix-huit mille mineurs de charbon ont été tués par des coups de poussières.

MONTAGE DE L'EXPÉRIENCE : 300 livres de poussière de charbon de Pittsburgh ont été placées sur des étagères le long de l'entrée de la galerie. On a utilisé du Primacord pour disperser la poussière puis de la dynamite pour enflammer la poussière.

Mélange : poussières de charbon de 74 microns et 6,5 % de méthane.

RÉSULTAT :

Coup de poussières très violent - A brisé tous les instruments, arraché les parois en béton, arraché le bois de construction qui a bloqué l'entrée, brisé des fenêtres 7 milles à la ronde et pouvait être entendu à 30 milles à la ronde.

Actuellement, on n'effectue que des expériences avec des petites explosions qui créent une pression de 1 lb/po^2 à l'entrée; il ne doit pas y avoir d'inversion de température : on surveille de près les conditions atmosphériques avant la mise à feu d'un coup de poussières.

EXPLOSIONS DE POUSSIÈRES SULFURÉES :

On a obtenu 500 livres de la Brunswick Mining and Smelting contenant 1 % de Cu, 10,9 % de Zn et 37 % de S.

Les explosions ont été simulées dans une enceinte d'essai, 5000 joules étant la limite supérieure; il a fallu 550 g/m^3 pour maintenir la propagation (à 30 % de S, 670 g/m^3)

DIAGRAMME : PRESSION EN FONCTION DE LA CONCENTRATION DE POUSSIÈRES

La courbe montre que la poussière de charbon est plus explosive que les schistes bitumineux à 44-50 gpt et à 35 gpt, avec les sulfures en-dessous de ce niveau.

ESSAI DANS LA MINE : utilisant la poussière restante, on a chargé l'ouverture avec des poussières, dispersé les poussières puis amorcé avec 1/2 lb d'Anfo. Des transducteurs, détecteurs, etc. ont été utilisés pour mesurer la pression et la vitesse de propagation. (700 à 800 mg/l pour la propagation d'un coup de poussières sulfurées).

RECHERCHE SUR LES SCHISTES BITUMINEUX : centaine d'essais, différente taille de particules, etc. au Colorado, pour mettre au point des caractéristiques.

MINE COLONIE, EXXON : Collecte de données

Trou de mine de 4,25 po de diamètre, 4200 tonnes par tir, tir de plein front par chambres et piliers, grandes ouvertures, pré-clivage des parois, B-cut, trou de 30 pieds, explosif Anfo, accélérateurs de 1 lb, sans bourrage, nonel avec E-cord. couvercles n° 8, 600 ms, fortes concentrations de poussières.

Instruments installés dans l'ouverture, film rapide pour enregistrer le tir.

Pressions, vitesses du vent, etc. mesurées (les forces du vent peuvent être un facteur important dans la dispersion des poussières pour obtenir une propagation pleine grandeur).

DIAGRAMME : CHARGE DES POUSSIÈRES SUR LE PLANCHER/CONCENTRATION NOMINALE DE POUSSIÈRES EN FONCTION DE LA DISTANCE DU FRONT DE TAILLE

À ce jour, rien n'indique que les concentrations sont importantes pour une propagation pleine grandeur.

CALCUL À POSTÉRIORI : 1 lb/po^2, équivalent une vitesse du vent de 55 pi/s environ

Conclusions :

1. Il semble que les poussières sulfurées soient un matériau plus difficile à enflammer et beaucoup moins violent que les poussières de charbon.

2. L'influence du méthane sur les coups de poussières de schistes bitumi- neux semble être importante; varie entre 18 et 60 pi^3/tonne de méthane.

3. Plus les particules de poussières sont petites, moins il faut de matériau pour créer un risque de coup de poussières et plus la probabilité d'inflammation est grande.

2. K. BYBERG - CHEF INGÉNIEUR, NORANDA INC. - DIVISION GECO

COUP DE POUSSIÈRES SULFURÉES DE LA GECO - 8 OCTOBRE 1985 À 23h55

HISTORIQUE

Le corps minéralisé de Geco, gisement lenticulaire renfermant du Cu, du Zn et de l'Ag, présente un pendage abrupt et plonge à 35° vers l'est sur environ 5500 pi.

Les réserves sont de 55 millions de tonnes; on a exploité jusqu'à aujourd'hui 42 millions de tonnes. L'extraction se fait au rythme de 4100 tonnes par jour.

On exploite actuellement la mine à partir de deux puits : le puits n° 1, situé à l'extrémité ouest du gisement, qui atteint le niveau 2450 pieds, et le puits n° 4, situé à l'extrémité est du gisement, qui atteint le niveau 4050 pieds. Les deux sont à poulies de frottement koepe.

La méthode d'extraction actuelle est le trou de mine sous le remblayage. Voici les dimensions d'un chantier type : 70 pieds suivant la direction, 80 pieds d'épaisseur et 400 pieds de hauteur. Les piliers mesurent 120 pieds suivant la direction, les autres dimensions sont les mêmes que précédemment. On creuse une saignée au centre du chantier d'où on enlève 20 % avant de pratiquer le sautage pour le reste du minerai.

La production se fait au moyen de racleurs de 125 HP qui déversent dans des convoyeurs situés au fond de chaque cage d'extraction le minerai sous le stérile de la carrière introduit par le sommet. Un programme de soutirage permet de régler la vitesse de descente de l'interface minerai/stérile. Il est conçu pour chaque chantier et dépend de la forme, de la taille, etc. de ce dernier. Il est mis à jour pendant toute la vie du chantier par ordinateur. Des résidus de cimenterie ou tout simplement le remblayage hydraulique est utilisé pour consolider les roches de la carrière pour qu'elles restent stables après l'extraction du minerai.

Le 8 octobre 1985 à 23h55, le tir de bouchon n°23 au sous-niveau 24-46 du pilier 26-46 a été effectué à partir de la surface. On avait évacué tous les employés de la mine à l'exception de l'équipe de galerie de trois hommes au niveau de 3850, 1400 pieds au-dessous du tir. Une cheminée de remblayage a été sautée à partir du niveau de 2350 directement, au-dessus du tir de bouchon. Ce procédé n'était pas courant à la Geco.

On fait circuler entre 10 000 et 20 000 pi^3/min d'air dans le chantier à partir du niveau 2450, avec 10 000 à 20 000 pi^3/min passant par chaque niveau. La teneur en soufre dans le chantier est de 28,3 % et c'est le plus grand chantier dans l'histoire de Geco (925 000 tonnes). Les deux chantiers situés de chaque côté sont exploités et remplis de résidus cimentés. Les teneurs des deux chantiers exploités antérieurement sont les mêmes que celui du 26-46, mais il n'y a eu aucun coup de poussières sulfurées dans ces chantiers.

Le coup de poussières sulfurées a renversé momentanément le sens de la ventilation. Des morceaux de la porte d'aération détruite ont été trouvés à une grande distance de son point d'installation, en sens inverse de la circulation de la ventilation.

L'apport de la ventilation totale est de 500 000 pi^3/min passant par le montage d'aérage du puits n° 1 (200 000 pi^3/min) et par le puits n° 4 lui-même (300 000 pi^3/min). Le puits n° 1 joue le rôle de puits de retour d'air, et il existe une tuyauterie d'aération dans le puits n° 4 qui aspire 60 000 pi^3/min des niveaux inférieurs.

Le SO_2 a été vers le bas dans la cheminée principale à minerai du niveau 2650 au concasseur du niveau 3850, à travers une quantité inconnue de déblais au-dessus de la cale de serrage et dans la galerie. En général, 10 000 pi^3/min circulent dans la galerie et sont évacués par la tuyauterie d'aération du puits. Dans ce cas, l'air a été refoulé vers le ventilateur de la galerie d'où il a été repris et envoyé à l'équipe de la galerie. Il y a eu un mort et deux blessés graves.

Des poussières fraîches se sont répandues autour du plancher du concasseur, etc., ce qui indique qu'il y a eu une très grande force derrière l'onde de choc de compression, ou front de choc.

CONCLUSION :

On pense que le tir de bouchon a été à l'origine d'un grand apport de poussières et que la cheminée de remblayage a été en flammes pendant 500 ms après la fin du tir.

3. LUCIEN NEL, INGÉNIEUR DE VENTILATION, SHERRITT GORDON MINES LTD., EXPLOITATION RUTTAN

On a élaboré des mesures pour réduire au minimum les coûts de reconstruction, les pertes de production, et prévenir les blessures, etc., mais elles restent encore insuffisantes.

La mine Ruttan a d'abord été exploitée à ciel ouvert; mais en 1979, elle a été transformée en mine souterraine, avec une extraction quotidienne de 6000 tonnes.

Le gisement de Cu-Zn est constitué de lentilles, les lentilles est et ouest étant les principales zones d'extraction.

La lentille est est celle qui nous préoccupe le plus à cause des sulfures qui s'enflamment, mais il y a eu aussi quelques incidents dans les autres lentilles.

Le gisement renferme un grand nombre de lentilles de pyrite, atteignant parfois 100 % de minerai dans l'horizon minéralisé de la lentille est. La teneur en soufre varie entre 43 et 53 % pour les pyrites dans toute la mine. La pyrite de la lentille est est recristallisée en grains plus gros et se fragmente très facilement, donnant ainsi naissance à de fines poussières.

EXTRACTION : On utilise des trous de mine de 4,5 pouces et de 6,5 pouces de diamètre pour les chantiers d'abattage. On utilise une foreuse pour montage pour couper le montage de havage après quoi on fait sauter les trous pour former un vide. Tout le chargement des roches se fait au moyen d'une chaîne à godets à partir du fond du chantier. Ce dernier est toujours ouvert; ce n'est pas un réservoir mais un système ouvert.

Les explosifs sont tous constitués d'une variété non combinée avec l'aluminium. On utilise du calcaire agricole pour bourrer tous les trous; tous les tirs se font à l'heure du changement de poste lorsqu'il n'y a plus personne dans la mine.

AÉRATION : La circulation de l'air se fait généralement de l'est vers l'ouest et du mur vers le toit. L'échappement se trouve au toit et les entrées d'air au mur. Ainsi, il y a de bonnes chances que les coups de poussières sulfurées n'arrivent pas au chantier principal.

Dans la mine inférieure, la mise en valeur n'a pas été terminée et ces passages pour la circulation d'air n'ont pas été établis. Toute l'aération se fait au moyen de systèmes auxiliaires. Lorsqu'il se produit un coup de poussières sulfurées, les systèmes auxiliaires sont endommagés et des poches de SO_2 se forment. Ce phénomène influe sur la production et est la cause de retards prolongés.

TIRS : On utilise un bouchon en bois au fond, 3 pieds de calcaire, une colonne de charge de nilite et 10 pieds de calcaire comme bourre. On accroche aussi des sacs de 10 à 15 livres de calcaire dans le chantier.

CAS CONCRET : CHANTIER D'ABATTAGE 26J - LE PLUS RÉCENT ET LE PLUS VIOLENT

22 juillet 1986 à minuit.
Première indication, la cage remonte après un tir en entraînant une longueur de 50 pieds de la gaine d'aération de 42 pouces. Cette gaine a été soufflée du chantier d'abattage vers la recette 730 du puits. D'autres tuyaux ont été trouvés dans le puits et la recette.

Deux ventilateurs de retour d'air ont été soufflés de leurs montages et déportés de 22 pieds.

Il a fallu cinq postes de travail pour remettre en place le système d'aération de la mine inférieure. Il n'y a pas eu de blessés.

Plus la mine est profonde et plus fréquents sont les coups de poussières.

Un contrat a été passé avec M. Hall, U C.-B., pour effectuer des recherches et établir un programme de surveillance pour la mine Ruttan (7 étapes).

EFFETS DES COUPS DE POUSSIÈRES SULFURÉES

1. Coûts : dégats matériels

2. Sécurité

3. Pertes de temps

MOYEN DE DÉFENSE

Essayer de limiter le temps de retard à 200 ms, on pourrait ainsi empêcher la situation de devenir optimale pour un coup de poussières sulfurées.

On utilise des explosifs sans aluminium pour avoir une température d'amorçage minimale.

On descend un brumiseur dans tous les chantiers d'abattage pour mouiller le chantier pendant 8 à 16 heures avant le tir (on garde le calcaire sec en le plaçant dans des sacs en plastique).

On adopte une méthode différente pour chaque tir, en tentant de prévoir au moyen de techniques analytiques les conditions possibles des coups de poussières. On évalue les résultats, s'il y a un coup et, par l'analyse des paramètres du coup, on essaie de prévoir les coups possibles à partir de conditions historiques, etc.

4. J. WOTTON, DIRECTEUR DU DÉPARTEMENT DE SANTÉ, SÉCURITÉ ET FORMATION, MATTABI MINES LTD.

Dans les 10-12 dernières années, il y a eu un grand nombre d'explosions secondaires.

Nous examinerons uniquement les 10 incidents les plus récents :

1. 16 octobre 1980 - Volée dans une galerie de mise en valeur, 3 hommes gazés, bourrage au calcaire.

2. 1981 - Volée dans une galerie, forte teneur en SO_2 après l'explosion, aucune autre indication.

3. 1981 - Trop forte charge dans du sable, 50 lb d'Amex, S à 35 %, tuyau endommagé et poussières rouges trouvées.

4. Septembre 1981 - Cheminée de remblayage, seconde explosion, aucune précaution prise avant le tir, zone pauvre sans aucun problème au préalable.

5. Octobre 1982 - Tir dans un chantier d'abattage, 1500 tonnes sautées, calcaire et pulvérisateurs utilisés, uniquement les tuyauteries d'aération ont été endommagées. Les points de soutirage de minerai du chantier étaient vidés, il y avait de grandes quantités d'air qui circulaient dans le chantier (la recommandation a été que les points de soutirage de minerai devaient rester pleins).

6. Octobre 1982 - Tir des poteaux dans le point de soutirage de minerai, 12 cartouches de poudre, amorçage de la surface, aucune précaution prise avant le tir. Les cales de serrage ont été endommagées, les canalisations d'air et d'eau déplacées.

7. Avril 1985 - Lyon Lake - Volée dans une sous-galerie; le cordeau détonant a explosé; un homme commotionné, poussières rouges.

8. Octobre 1985 - Présumée, mais aucune indication.

9. 1986 - Tirs primaires dans les chantiers d'abattage, toutes les précautions prises.

10. 1986 - Tirs primaires dans les chantiers d'abattage, toutes les précautions prises.

Les incidents de Mattabi couvrent une grande gamme de situations, surtout pendant des travaux de préparation avec différents explosifs, temps, etc.

On pense qu'il y aurait lieu d'utiliser un formulaire normalisé pour enregistrer ces incidents : la MAPAO pourrait être une bonne source.

Il y aurait lieu de rassembler l'information, avec les matériaux de toutes dimensions; de la taille du poing en descendant.

Le mouillage est l'opération la plus critique; ceci est valable aussi pour les sacs de calcaire.

Le bourrage au calcaire et le bourrage à l'eau ont été essayés dans des trous chargés.

Marche à suivre pour des volées dans des galeries - laver soigneusement, bourrer avec Anfo au calcium et suspendre des sacs de calcaire qui seront crevés avec la première charge explosive.

DIFFÉRENCES AVEC LES AUTRES PROPRIÉTÉS

Aucune enceinte de confinement dans certains endroits et aucune explosion secondaire pour faire partir la poussière.

RÉSULTAT :

Renseignements insuffisants sur les paramètres réels d'amorçage pour prévoir les explosions.

Il existe un lien entre la teneur en soufre, au-dessus de 29 % de S, et les coups de poussières, mais un grand nombre de mines avec des pourcentages supérieurs à 29 % de S n'éprouvent aucun problème.

M. R.J. ENRIGHT - DIRECTEUR DU DÉPARTEMENT DE GÉNIE MINIER - UNIVERSITÉ DE SYDNEY

Les coups de poussières sulfurées ont été passés sous silence dans la plupart des cas jusqu'à ce jour.

DEUX CAS CONCRETS DE COUPS DE POUSSIÈRES :

1. MINE ELURA, NOUVELLE GALLES DU SUD

Il n'y a pas eu de blessés.

CORPS MINÉRALISÉ : Forme élliptique, la pyrite, l'arsénopyrite, la pyrrotite, la sphalérite et la galène sont les principaux minéraux. Le corps minéralisé se divise en trois zones : à pyrite, à pyrrotite et siliceuse.

ANALYSE DU MINERAI :

S	30-37 %
Fe	24-30 %
Zn	9-13 %
Pb	5-9 %
Silice	0-23 %

30 novembre 1983 : premier coup de poussières enregistré (il y en a eu un par an, depuis 1984 et 1985)

Dégâts : L.H.D. de 12 tonnes et compresseur détruit.

Octobre 1985 : fait sauter 4 trous - 300 kg de dynamite gélatineuse et 2150 kg d'Anfo dans des trous de 200 mm de diamètre et de 15 à 43 m de long. On a utilisé du bourrage au calcaire et de 400 mm à 4,5 m d'un autre bourrage.

Dégâts : peu importants, mais il y a eu un retard de 4 h dans la mine. On avait utilisé des pulvérisateurs d'eau dans les zones de tir.

2. MINE LANGSELE, SUÈDE - 23 MAI 1969

Deux mineurs tués, dégâts importants dans 3 niveaux de la mine.

CORPS MINÉRALISÉ - minerai complexe de pyrite, extraction de la pyrite pour alimenter une fonderie.

ANALYSE DU MINERAI :

Cu	0,85 %
Zn	3,84 %
S	38,7 %

Au moment de l'accident on utilisait le dépilage par sous-niveau, mais, depuis, on utilise l'abattage par tranche montante remblayée. Le 13 mai 1969, on a préparé un sous-niveau pour un tir, chargé des trous de 45 mm avec de l'Anfo et des amorces pour dynamites; la plupart des charges n'ont pas explosé.

Le 14 mai, on a replacé des cordeaux aux ratés qu'on a tirés de nouveau; là encore on a eu la moitié de ratés.

Le 23 mai, les trous ratés, contenant 800 kg d'Anfo, ont été vérifiés et puis tirés de nouveau. Deux boutefeux étaient dans la mine pour faire détoner le tir et aller à un autre niveau pour faire détoner un tir du montage. Tous les autres mineurs ont été évacués. Faire détoner le tir d'abattage au niveau 210 puis prendre la cage jusqu'au niveau 260 pour faire détoner le tir de montage.

Le premier tir a été mis à feu et peu de temps après, le coup de poussières s'est fait avec une telle force que le machiniste d'extraction a été blessé. Le contremaître a revêtu son équipement de sauvetage et a grimpé jusqu'au niveau 210 où il a trouvé les deux boutefeux allongés dans la cage. Ils étaient morts une fois remontés en surface, leur cage thoracique était endommagée : on ne sait pas si c'est par le SO_2 ou à la suite d'un coup.

La mine a été fermée pendant deux semaines pour la réparation des dégats.

Depuis, on ne fait que des tirs secondaires dans la mine souterraine, tous les autres tirs sont mis à feu à partir de la surface et la mine est évacuée.

STATISTIQUES DES COUPS DE POUSSIÈRES SULFURÉES

Les statistiques qui existent sur ces événements sont très minces.

On a signalé 10 morts - 7 par le SO_2
14 blessés - 13 par le SO_2.

Ces coups de poussière sont aussi fréquents dans les tirs en chantier que dans les tirs au cours des travaux préparatoires.

D'après les statistiques, la plupart des blessés le sont par inhalation et non par les dégats mêmes du tir.

TROIS ÉTAPES SONT ASSOCIÉES AUX COUPS DE POUSSIÈRES

1. Front des flammes - 1000 °C
2. Front des flammes avançant rapidement 20-300 m/s
3. Augmentation de pression - dégâts matériels, etc.

Des essais à 100 kpa (14,5 lb/po^2) ont fait des dégats dans un béton de 4 po d'épaisseur.

À 1,5 lb/po^2 on constate des blessures et des lésions.
Produits de combustion - SO_2, Co, H_2S (combinés à un manque d'oxygène).

On a effectué dans les mines de charbon beaucoup plus de travaux, qui ont une relation avec des mines sulfurées!
Toutefois, certaines techniques utilisées dans les mines de charbon ne peuvent pas toujours être appliquées aveuglément, les solutions ne sont pas transférables, en raison des différences des ordres de grandeur.

MINES DE CHARBON :
Au début des années 1800 : introduction de la poudre à canon et augmentation des coups de poussières.

On a appris que le méthane était la cause des coups, on a alors fait appel à des boutefeux qui enflammaient les poches de méthane dans les lieux de travail.

En 1815, on a introduit les lampes de sécurité.
En 1844, Faraday a reconnu que les poussières de charbon étaient explosives; ceci n'a pas été accepté mais a été prouvé en 1909.

On a utilisé des poussières de calcaire (poussière de pierre) pour réduire les coups; l'extraction en surface était moins cher, le blanc était une bonne couleur pour la réflectivité et comme marqueur pour déterminer les zones empoussiérées. Le calcaire n'a aucun effet sur la santé.

Plus récemment, dans les années 70, des coups de poussières de charbon, pas de CH_4, ont été la cause d'un grand nombre d'incidents.

Dans la Nouvelle Galles du Sud, l'exploitation minière pendant 50 ans s'est effectuée sans accident, mais en 1979, 14 personnes ont été tuées. Par conséquent, ce n'est pas parce qu'il n'y a pas de catastrophe qu'on peut dire que cela ne peut se produire.

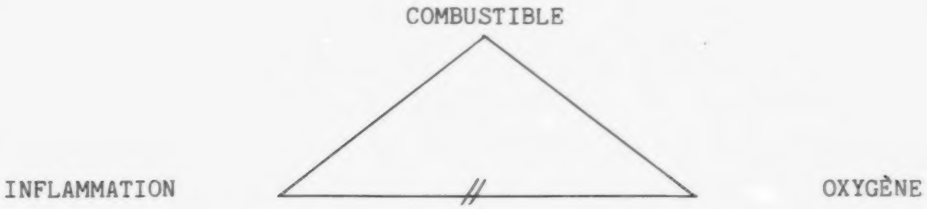
La poussière de céréales a aussi été une source potentielle de catastrophe pendant longtemps, mais cela n'a été reconnu qu'en 1977.

MÉCANIQUE - FACTEURS ASSOCIÉS AUX COUPS DE POUSSIÈRES DE CHARBON

Combustion très rapide.
Différence entre incendie et explosion (les deux ont besoin des mêmes constituants) - vitesse à laquelle l'énergie est libérée.
N'importe quelle matière qui brûle peut exploser.

POUR LES COUPS DE POUSSIÈRES :

1. La poussière doit être finement divisée et en suspension (n'explose pas si elle n'est pas en suspension)
2. Il faut un agent oxydant.
3. Il faut une source d'inflammation.
4. Il faut un espace confiné.



Il faut briser la chaîne à un point quelconque pour éliminer le problème.
Briser la chaîne à tous les points possibles est encore mieux.

L'aérage permet habituellement de prévenir les incidents, mais dans une mine ce n'est pas facile.

FACTEURS QUI INFLUENT SUR L'ÉVOLUTION ET LA SÉVÉRITÉ DES COUPS DE POUSSIÈRES

1. COMBUSTIBLE

Composition chimique, % de pyrite et % d'autres formes de S (galène, sphalérite, chalcopyrite, etc., aussi explosives), on devrait par conséquent tenir compte de toutes les formes de S.

Additionner un matériau inerte - si la poussière a la même composition chimique que la roche.

La poussière rouge, si souvent utilisée comme indicateur, provient en fait de la dernière réaction chimique de la chaîne - le soufre peut être présent sans qu'il y ait formation d'hématite.

La magnétite est présente et constitue le premier produit de la réaction.

Dans la chambre à combustion expérimentale :

Essai en vue de produire une courbe de la pression en fonction du temps

Le rapport $\frac{DP}{DT}$ donne une indication de la grandeur.

Courbes :
- pression max. en fonction de la concentration des poussières
- augmentation de pression max. en fonction de la concentration de poussières

(Addition de poussière de roche) - pression max. obtenue en fonction de la concentration de poussières

(Dans des conditions expérimentales, on peut obtenir un coup de poussières avec n'importe quelle addition de matériau inerte), par conséquent, le calcaire ne résout pas le problème lorsqu'on l'utilise comme moyen de prévention.

TAILLE DES PARTICULES Les particules plus petites sont plus inflammables, la superficie accrue est critique.

DÉFINITION DES POUSSIÈRES (CHARBON)

Plus petites que 75 microns à 90 microns (plus grandes peuvent encore être explosives)

La superficie peut être grande si un grand nombre de vides est présent sur les particules.

Répartition de la taille des particules - les petites particules s'enflamment facilement et peuvent enflammer les plus grandes particules.

Vitesse de décantation est plus petite pour les petites particules, mais la densité de poussières est critique dans ce cas.

VARIABLES QUI ENTRENT EN JEU :

Limites d'explosibilité inférieure et supérieure

Méthane	CH_4 - 5 à 15 %
Pétrole	∿ 8 à 50 %

mais, le gaz occupe tout le volume.

La poussière n'occupe pas tout le volume, il est difficile d'établir des limites, par conséquent pas de limite vraie supérieure.

La poussière peut être résiduelle ou produite :
La poussière résiduelle occupe les parois, le plafond et le mur, est consi- dérée comme explosive si on peut l'enlever avec le doigt, 500 g/m^3 - il ne faut par conséquent qu'une très petite quantité.

2. INFLAMMATION

Température d'inflammation et énergie minimales

- les mélanges gazeux s'enflamment très facilement dans les mines de charbon
- toutefois, dans les mines de roches dures il y a de grands volumes de ce matériau, mais les grandes volées ont du matériau non explosé qui continue à brûler, etc.

3. OXYGÈNE

*N'est pas commode dans les lieux de travail.

FORME ET TAILLE DE L'ESPACE CONFINÉ

La taille du chantier et l'aérage nécessaire pour une forme de chantier particulière sont importants.

La direction de l'explosion est imprévisible.

COUPS DE POUSSIÈRE PRIMAIRE ET SECONDAIRE

(Primaire se rapporte au premier coup de poussières, sans tirs d'explosifs)

Le coup de poussières primaire est généralement de faible nature, mais dérange la poussière et la flamme allume la poussière maintenant dispersée.

Le front de choc est plus rapide, 374 m/s, alors que le front des flammes commence lentement à 50 m/s.

À mesure que le front des flammes s'accélère, le front des flammes et le front de choc se rencontreront et on doit par conséquent épandre le matériau inerte, etc. à des intervalles convenables pour empêcher le déclenchement du coup de poussières secondaire.

Dans l'abattage par sautage, il est impossible de prévenir la formation de la poussière de roche, mais le lavage de toutes les galeries effectué pour éliminer la poussière et la rendre inerte est possible.

D'une manière générale, le mécanisme dans la roche dure est différent de celui dans le charbon. Le tir aux explosifs après que le premier nuage de poussière se soit formé pourrait être un problème possible.

ÉQUIPEMENT D'ESSAIS EN LABORATOIRE

Chambres d'explosion pour évaluer la concentration de la limite d'inflammabilité de la poussière et la mesure des pressions, etc. :

1. Fonction de la taille et de la forme du récipient
2. Fonction du système d'épandage de la poussière
3. Fonction du système d'inflammation, de l'emplacement et de la température, etc.

Les résultats sont fonction de la chambre et on obtiendra des résultats différents pour des chambres différentes.

Mesurer la pression max. et la vitesse de l'augmentation de pression.
La vitesse d'augmentation de pression est fonction de l'énergie d'inflammation.
Effectuer un certain nombre d'essais à différentes concentrations de matériau inerte ajouté : c.-à-d. poussières de roche, sable rouge, sel, etc.
Tracer les courbes d'augmentation de pression en fonction des matériaux non combustibles dans les mélanges.
Les résultats révèlent que tout matériau inerte est important et que le calcaire n'est pas le seul matériau disponible.

Le calcaire sert à :
1. absorber l'énergie,
2. protéger contre la chaleur
3. empêcher la combustion
4. augmenter l'énergie minimale d'amorçage.

ANALYSE DES POUSSIÈRES APRÈS LES COUPS

Réduction très importante du S pour des concentrations moins denses à l'origine, mais ce n'est pas un indicateur lorsque les fortes densités sont communes.

L'énergie d'inflammation est un facteur important à considérer quand on cherche à obtenir un mélange non explosif.

La pression maximale est produite avec de la pyrite pure dont la teneur en S passe de 52 % à 30 %; aucune explosion ne se fait à moins de 20 % de S, mais entre 26 % de S et 30 % de S la courbe a une pente forte et est très sensible au changement des paramètres (environnement), et on peut avoir des coups de poussières violents.

Le mélange réel du nuage de poussières n'est pas un mélange intime - 60 g de poussière incombustible pour 100 g de minerai à 32 % de S. Il est important de savoir quelle est la quantité de poussière qui se produit et où elle se produit, et si tous les chantiers sont propres. En supposant qu'il se produise 25 mm de matière pulvérisée autour du trou de mine après le tir, une courbe montrant la poussière produite en fonction du matériau inerte nécessaire pour rendre inerte 50 % de poussière permet d'estimer la quantité de matériau inerte par m de trou de mine tiré.

La longueur du bourrage au calcaire est presque égale à la longueur de la colonne d'explosifs, et il est donc très difficile de justifier l'emploi de calcaire; fragmentation, charge, etc.

ADDITIONS D'EAU

Les pressions maximales baissaient à mesure que la teneur en eau augmentait.

Eau libre : absorbe la chaleur du front de flammes
a une chaleur de vaporisation
ne peut servir comme bouclier thermique

Sert pour lier les particules et diminuer les pressions à la suite de la formation de particules plus grandes.

Les inclusions d'eau peuvent donner naissance à la formation de H_2S.

5. F. HERMANN - INGÉNIEUR D'ÉTUDES PRINCIPAL, BRUNSWICK MINING AND SMELTING

Les coups de poussières sulfurées n'ont pas été un problème important.

La plupart de ces coups de poussière se sont produits au niveau de 1000 m au cours des trois dernières années.

Ils ont commencé pendant la phase des travaux préparatoires, étaient très communs lorsque des fronts multiples étaient très rapprochés, généralement faisant des dégats dans les conduites d'aérage.

La pyrrhotite semble constituer entre 8 et 9 % dans cet endroit; l'accumulation de poussières présente un problème.

Des coups de poussières se font dans d'autres secteurs, mais uniquement là où le taux de pyrrhotite est élevé.

On se sert de l'eau pour laver toutes les fendues à 100 pi du front.

On utilise de l'eau pour bourrer tous les trous, des sacs de calcaire sont accrochés à 20 pi du front, et on laisse des pulvérisateurs d'eau à 20 pi du front, derrière le calcaire.

On n'observe plus systématiquement les précautions, mais uniquement dans les secteurs à forte teneur en pyrrhotite; la proximité de fronts multiples n'est plus un problème.

Les coups de poussières sulfurées sont réduits au minimum dans les tranches montantes remblayées à cause de l'exploitation cyclique; le lavage du minerai abattu pour le chargement, le boulonnage, etc., de l'eau est donc présente.

On est passé aux longs trous au niveau de 1000 m, mais avant l'exploitation par tranches montantes remblayées on faisait déjà des longs trous.

Le chantier d'abattage (partiellement abattu) a été abandonné pendant 5 ans.

Le chantier n'a pas été lavé avant le tir; lorsque les premiers trous de mine ont été tirés, il y a eu un coup de poussières sulfurées. Les cloisons d'aérage ont été détruites, les glissières de guidage des bennes d'extraction déplacées dans le puits, l'équipement a bougé, expulsion de SO_2, etc.

Après ce qui s'est passé, il a fallu suivre un programme avant les tirs.

1. Prélavage de toutes les zones aux environs du tir.
2. Suspension de sacs de calcaire dans les accès
3. Suspension de sacs de calcaire dans les chantiers d'abattage
4. Pulvérisation d'eau dans les accès et le chantier d'abattage

QUESTIONS POSÉES PAR LE GROUPE

Q. Y a-t-il une relation entre la pyrrhotite et les coups de poussières sulfurées (ce qui est aussi un problème d'oxydation)?

R. Il exite peut-être une relation.

Q. Combien de calcaire place-t-on et où?

R. Le chantier est entouré de calcaire pendant les tirs; il est accroché dans le chantier, derrière l'emplacement du tir dans les galeries et dans les trous à tirer, au total au moins 500 lb.

Q. Se sert-on d'explosifs à base d'aluminium?

R. Non.

6. K. CASEY - DIRECTEUR NATIONAL DE LA COMMERCIALISATION, DUPONT CANADA INC.

COUPS DE POUSSIÈRES

Facteurs principaux - Utilisation des propriétés des explosifs simulées dans le modèle informatique "BLASPA"

Les simulations couplent la thermodynamique des explosifs et les propriétés et la configuration des roches.

T/D - température de détonation - atteint 5000 K à l'intérieur de l'explosif et seulement pour une courte durée - 5×10^{-6} s.

T/X - température de l'explosion - plus longue durée.

La température de la détonation est prise à l'amorçage et la température de l'explosion est atteinte pendant le déplacement du front de flammes.

Aucune des températures ne semble être un bon critère pour prévoir un coup de poussières.

PRINCIPAL MÉCANISME D'UN TIR

Premièrement : forte onde de compression qui part de l'explosif.

Deuxièmement : ondes de tension réfléchies sont à l'origine de la fracturation (la roche est généralement faible en tension).

La première étape est celle pendant laquelle il y a production de poussière dans le trou et la roche est intacte.

L'onde de tension est à l'origine de la fragmentation primaire, la fragmentation secondaire étant produite par la pénétration du gaz qui avance vers un front libre pour s'échapper; le cratère formé n'a qu'un seul front pour l'échappement des gaz alors qu'une entaille en a plusieurs.

T/E - température des gaz, est plus faible que T/X

La température des gaz d'échappement T/E à l'interface gaz/poussière/roche dure jusqu'à la dissipation (ce n'est pas un temps court)

$$T/E < T/X < T/D$$

Dans un tir particulier, voici les facteurs qui influent sur T/E

1. Type de roche
2. Type d'explosif
3. Distribution de la charge
4. Matériau de bourrage
5. Bouche du trou, espacement, longueur du trou
6. Le couple explosif/roche

T/E peut varier avec les facteurs susmentionnés - mais pas la température de l'explosion.

Il y aurait lieu de considérer cette température de gaz d'échappement comme un facteur important pour les coups de poussières - non comme un facteur lié à l'explosif seul mais à l'utilisation de l'explosif - qualité rapportée au potentiel.

MODÈLE "BLASPA"

1. On a besoin des propriétés élastiques de la roche pour la simulation : module de Young, rapport de Poisson, etc.

2. La géométrie des tirs est nécessaire pour la simulation.

3. Type d'explosif.

   On peut effectuer des simulations pour les différents types de bourrage.

RÉSULTAT: AUGMENTATION DU BOURRAGE - T/E est réduite de 800 K, lorsque le bourrage atteint une longueur spécifique, puis ne baisse plus.

LONGUEUR DE LA CHARGE - réduit T/E, mais pas beaucoup.

TYPE D'EXPLOSIF - longueur de charge fixée, le bourrage varie de 0 à 41 lb - l'addition d'aluminium ou d'autres agents similaires augmente la T/E.

Par conséquent le bourrage est critique - la T/E est élevée lorsque l'Anfo n'est pas accompagné de bourrage et est plus élevée que pour des dynamites gélatineuses légèrement additionnées d'aluminium.

QUESTION GÉNÉRALE

Quelle est la température d'inflammation de la poussière sulfurée et quel lien a-t-elle avec la T/E?

À la Ruttan (Sherrit Gordon), on a utilisé une température estimée de 1700 K; cette donnée est fondée sur des explosions d'essai obtenues à 1900 K et aucune explosion à 1500 K, en moyenne.

NOTE : Toutes les simulations se rapportent au tir qui donne un cratère, mais on peut aussi simuler les entailles.

La bonne pratique requiert un tir sans accident, mais exige des résultats acceptables; fragmentation etc., par conséquent il faut des explosifs d'une certaine force minimale.

RÉSUMÉ : Les deux facteurs les plus importants semblent être le bourrage et le type d'explosifs pour contrôler la température des gaz qui s'échappent, cette température est en fait un moyen de contrôle des coups de poussières.

Bourrage : a fonction principale de contenir les gaz, et joue en fait le rôle d'un puits thermique.

QUESTIONS POSÉES PAR LE GROUPE :

Q. Pourquoi a-t-on utilisé du sel comme additif à l'Anfo?

R. Parce qu'il joue le rôle de puits thermique et est 4 fois plus efficace que le calcaire.

Q. Quelle T/E doit-on prévoir pour obtenir l'écrasement?

R. La T/E devrait être plus élevée.

7. K. WHEELAND - CHEF DU DÉPARTEMENT DE TECHNOLOGIE DE L'ENVIRONNEMENT, CENTRE DE RECHERCHES NORANDA

1979 - Il y a eu des coups de poussières dans deux exploitations.

Des échantillons ont été prélevés de différentes propriétés de la Noranda pour les essayer dans des appareils explosimétriques.

Les diluants des différents types essayés, ont donné des résultats qui ne présentaient aucune différence; aucun diluant ne contenait du soufre.

On a déterminé la température d'inflammation de la poussière de sulfure à différents pourcentages de soufre.

Un questionnaire distribué, permettra de déterminer quel type de mesures préventives on utilise pour éliminer la probabilité des coups de poussières sulfurées.

L'eau et le calcaire ont été des matériaux très utilisés.
Pour la pulvérisation de l'eau, les avis étaient partagés.
On a mentionné le changement d'explosifs.
On a mentionné les tirs échelonnés.

FACTEURS ENTRANT EN JEU :

% de S, friabilité, retards de détonation, état poussiérieux, type d'explosif, méthode d'extraction, géométrie des chantiers.

MÉTHODES DE LUTTE CONTRE LES COUPS DE POUSSIÈRES :

Direction et qualité de l'aérage, évacuation du personnel de la mine, équipement enlevé des lieux, vérification la qualité de l'air avant d'entrer de nouveau.

RÉSUMÉ :

1. Il est important d'étudier d'une façon uniforme tous les accidents et de publier les résultats pour aider les autres compagnies.
2. Peut-être que Inco ou Falconbridge peuvent aider en répondant à quelques-unes de ces questions.

M. R.J. ENRIGHT

Corrélation des résultats de laboratoire avec les résultats sur le terrain.

- Il semble qu'il existe une corrélation dans les schistes bitumineux.

Lorsqu'un coup de poussières sulfurées se produit, quelle direction prend-il?

Cela permet de déterminer le point d'amorçage et la direction du front de flammes.
Avons constaté des réactions chimiques de SO_2 et des particules de pyrite le long de la trajectoire.
Le premier produit est la magnétite; on peut déterminer sa présence par un simple aimant dans la galerie.
Deuxième produit est l'hématite; la présence de cet dernier est difficile à déterminer, elle peut être rouge, brun, noir, etc.
L'analyse chimique n'est pas toujours confirmative.
Le microscope permettra une inspection visuelle des particules. Pendant la réaction du soufre, les particules deviennent sphériques et donnent des formes triangulaires bien nettes sur la peau avec un creux à l'intérieur. Un microscope normal de géologue est suffisant pour analyser les particules.

Y a-t-il des inconvénients à utiliser du calcaire dans les chantiers d'abattage comme substance inerte - $CaCO_3$.
Est-ce que le calcaire aura une influence sur l'usine de traitement si utilisé en grande quantité?

Dans la plupart des cas, les quantités spécifiées ne sont pas assez grandes pour avoir une influence sur l'exploitation.

Un coup de poussières pendant la mise à feu :

Ne peut se produire à l'intérieur d'une masse de matériau brisé, car il y a une trop grande quantité de roches inertes autour de la poussière.

Le mouvement d'une masse rocheuse est en fait bien défini avec une vitesse du front de tir et une vitesse de chute, par exemple

trou de 4,5 po de diamètre, 100 pi de long.
Morts terrains 7 pi; Anfo utilisé pour le tir
Calcul du front de $V = 60$ pi/s, $g = 32$ pi/s^2
9 pi de bourrage.
Masse rocheuse se déplace sur 60 pi en 1000 ms et tombe de 16 pi.
Masse rocheuse se déplacera pendant 750 ms avant que le bourrage soit complètement découvert, par conséquent 750 ms avant qu'une source d'inflammation soit exposée (gaz qui s'échappent sont discontinus, etc).
D'après les indications, la masse rocheuse se déplace vers le bas lorsque se produisent les coups de poussières sulfurées secondaires, par conséquent le front de flammes se déplace vers le haut du chantier d'abattage, étant donné que c'est le seul passage disponible.

Les calculs pour n'importe quel type de profil de tir sont possibles, mais pour des tirs dans les galeries c'est plus difficile.

L'aspersion d'eau dans les chantiers pendant les tirs est une pratique douteuse : suffit-elle à rendre le système inerte? Car les coups de poussières sont très violents et on ne laisse qu'une fine pulvérisation d'eau qui ne produit qu'une très petite quantité d'eau dans le chantier.

Le calcaire dans des trous de mine peut ne pas être aussi efficace étant donné que les pressions sur le bourrage pendant le tir se traduisent par des effets de compaction sur la colonne, effets qui peuvent produire des morceaux solides plus gros, capables d'annuler les effets de la poudre.

La Brunswick Mining a expérimenté la distribution du calcaire dans les galeries, autour des tirs et sa dispersion à l'explosif.

L'USBM a expérimenté l'eau et même l'eau chaude (jusqu'à la vapeur), pour rendre la poussière inerte. Les calculs montrent que l'on n'a besoin que de 1/60 de l'eau nécessaire quand cette dernière atteint la phase de vapeur.

Une question fréquente : les points de soutirage du minerai doivent-ils rester pleins ou vides?

Étant donné la toxicité du SO_2, devrait-on faire le tir juste avant l'entrée d'un poste ou laisser une période avant l'entrée dans la mine. Le contrôle surveillance peut aussi être fait avant l'entrée dans la mine. Le temps si la mine est restée vide devrait être suffisant pour laisser échapper le SO_2.

Il est important d'évacuer les ouvriers au moment du tir s'il existe un risque de coup de poussières.

Peut-être, dans certaines mines où se produisent des coups de poussière, on pourrait surveiller le retour des systèmes d'aérage pour déterminer quels sont les changements, s'il en existe, qu'on peut déceler dans les teneurs en SO_2 après des tirs importants.

La Geco est en train de mettre en oeuvre un système de ventilateurs télécommandé, surveillé par ordinateur, dont le but est de commander tous les ventilateurs d'aération à partir d'un ordinateur central. Ce dernier permettra d'enregistrer les interruptions de service, de mettre en marche des ventilateurs ou de les arrêter. Le système final permettra de surveiller les substances dans l'air de la mine. Les systèmes actuels de surveillance utilisés pour le SO_2 ne sont pas fiables.

L'installation d'un système de surveillance dans une grande mine serait très coûteuse pour couvrir d'une façon adéquate tous les chantiers de la mine.

Après l'accident de la Geco, il n'y avait aucune indication de SO_2 dans les lieux de travail après une courte période; cela démontre par conséquent qu'une grande mine peut s'aérer toute seule très rapidement et ne laisser que peu d'indices de l'importance du coup de poussières.

Notes prises par Douglas A. Sands